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SUMMARY

An effort is under way at Langley Research Center to improve the pilot-machine interface with aircraft automation to increase the safety and utility of single-pilot IFR (instrument flight rules) operations. As a means of improving this critical interface, an automatic terminal approach system (ATAS) was conceived that can automatically fly a published instrument approach by using stored instrument approach data to automatically tune aircraft radios and control an aircraft autopilot. The ATAS executes the missed approach procedure at the completion of the approach unless the pilot takes over to land. The system concept allows for easy pilot override to accommodate air traffic control radar vectors and altitude assignments. Emphasis for the design was a reduction in pilot workload and blunders by improving the pilot-automation interface.

A research prototype of an ATAS was developed for simulator implementation and evaluation. The ATAS was developed to the extent necessary for a simulation study and would require additional development prior to building a flight-quality research prototype. This report describes the development of the ATAS concept, software algorithms, and implementation in a general aviation simulator.

INTRODUCTION

General aviation instrument flight rules (IFR) activities currently involve approximately 18 million airport operations per year and are forecast by the Federal Aviation Administration (FAA) to increase to about 30 million operations per year by 1993. Most of these operations are conducted by nonprofessional single-pilot crews. These single-pilot crews are expected to perform at the same level as professional multipilot air-carrier crews. The high IFR accident rate during the approach and landing phase of flight, as documented in reference 1, indicates that the required level of performance has not yet been achieved. Improvements in aircraft handling qualities, displays, automatic flight control systems, training, and air traffic control procedures may be necessary to reach this level of performance.

Approach and landing is the phase of IFR flight with the highest workload. The pilot must navigate with higher precision than during the departure or en route phases. Air traffic control communications and frequency changes are more numerous. The pilot is making frequent changes in aircraft altitude, heading, speed, and configuration while in ever-increasing proximity to the ground. Checklists and navigation charts are read in detail. The pilot is in a highly dynamic situation with a high potential for mistakes and with limited time to detect and correct any errors. A successful arrival depends on the correct interpretation of approach chart details, the correct setting of numerous cockpit controls, and precise aircraft guidance near the ground.

Automation in the form of an autopilot has been utilized to reduce pilot workload and improve pilot performance in the terminal area. However, research studies (see ref. 2) and airplane accident and incident reports show that automation does not always improve pilot performance and may contribute to errors if the pilot-machine interface is not carefully designed. Conventional autopilot interfaces provide the pilot with many opportunities to make errors due to the requirements to change radio

frequencies and change autopilot modes as the approach progresses. An automatic terminal approach system (ATAS) concept was developed to study ways of significantly reducing the pilot's workload and error likelihood during terminal area operations by improving the pilot-machine interface. The ATAS stores instrument approach data and uses the data to automatically fly an instrument approach by tuning the aircraft navigation radios and controlling the aircraft autopilot. The ATAS is designed to fly according to the same rules and procedures that the pilot operates by in the present air-traffic-control (ATC) system. An automatic missed approach is executed if the pilot does not assume control at the missed approach point. Finally, the ATAS is designed for the real world environment of frequent ATC radar vectoring to a final approach course.

A simulated ATAS was developed and a research prototype was built in preparation for a future simulation study to evaluate pilot acceptance and the pilot-machine interface with such a system. There was no attempt to develop flight-quality hardware or software. The system was developed to the extent necessary to implement on the NASA Langley general aviation simulator for a planned piloted simulation. This report describes the design and implementation of the simulated ATAS.

ABBREVIATIONS

ADF	automatic direction finder
AKQ	identifier for Wakefield nondirectional radio beacon
ATAS	automatic terminal approach system
ATC	air traffic control
CDI	course-deviation indicator
CRT	cathode-ray tube
DH	decision height
DME	distance measuring equipment
ECDI	electronic course-deviation indicator
FAA	Federal Aviation Administration
FKN	identifier for Franklin VORTAC
HDG HLD	autopilot heading hold mode
HDG SEL	autopilot heading select mode
H.P.	holding pattern
HPW	identifier for Hopewell VORTAC
HSI	horizontal-situation indicator
IAF	initial approach fix

IFR	instrument flight rules
ILS	instrument landing system
LOC BC	autopilot localizer back-course tracking mode
LOC NORM	autopilot localizer front-course tracking mode
MDA	minimum descent altitude
NAV 1	number 1 VOR radio receiver
NAV 2	number 2 VOR radio receiver
NDB	nondirectional radio beacon
NM	nautical mile
OBS	omnibearing selector
PHF	Patrick Henry International Airport
P.T.	procedure turn
SBY	ATAS standby mode
seg	segment
VLDS	visual landing display system
VOR	very-high-frequency omnidirectional range
VORTAC	VOR with colocated ground DME facility

Flags:

AFLAG	approach flag, set on final approach segment
GRND	status of go-around button
HFLAG	indicates that aircraft heading has been latched for heading-hold mode
HOLD	status of hold button
HOLDFLAG	set at beginning of missed approach to set hold-button status true
LFLAG	set if ATAS becomes lost
NAVR	indicates to subroutine RADIO whether it was called to set up a radio for the autopilot or for navigational radio scanning
NTFLAG	set by subroutine RADIO if a tuning request must be denied
SPDFLAG	set at beginning of missed approach to activate autothrottle

TFLAGB	timer B runs if set
TFLAGL	timer L runs if set

Variables:

ALTA	actual aircraft altitude, ft
ALTC	commanded aircraft altitude, ft
ALTKNOB	value of control-panel, altitude-select knob setting
ALTM	status of altitude mode, either auto or manual
ALTP	altitude shown on control-panel CRT display
ALTS	altitude of current approach segment
APML	autopilot mode, lateral (either none, heading select, VOR track, ADF track, or localizer track)
APMV	autopilot mode, vertical (either none, altitude hold, altitude select, or glide-slope track)
APRL	autopilot mode request, lateral
APRV	autopilot mode request, vertical
CRSKNOB	control-panel, course-select knob setting
CRSM	status of course mode, either auto or manual
DIRA	direction to airport, deg
DISTA	distance to airport, n.mi.
DISTF	distance to Franklin VORTAC, n.mi.
DISTH	distance to Harcum VORTAC, n.mi.
DISTS	distance to Swing intersection
FREQC	command frequency for radio tuning
FREQ(RN)	frequency tuned on radio number RN
FREQ(RT)	frequency tuned on radio number RT
GSERR	angular glide-slope deviation, deg (positive above glide slope)
HA	actual aircraft heading, deg
HB	heading bug command for autopilot, deg
HC	command heading, deg

HCRS	course of holding pattern inbound leg, deg
HD	heading to be displayed to pilot, deg
HP	heading being displayed on control-panel CRT display
HPTIME	time flown on holding-pattern outbound leg, sec
HS	heading of current approach segment, deg
LSN	last segment number
MDA	minimum descent altitude, ft
MSG	message number for CRT line 1
MSGF	flashing message number for CRT line 1
OBS	omnibearing select (ground station radial to be tracked), deg
RADB	Wakefield beacon radial, deg
RADF	Franklin VORTAC radial, deg
RADH	Hopewell VORTAC radial, deg
RB	relative bearing from aircraft to station, deg
RN	radio requested for navigation; 1 = NAV 1, 2 = NAV 2, 3 = ADF, 4 = DME
RT	radio requested for autopilot tracking
SERR	error between command airspeed and actual airspeed, knots
SN	current segment number
SPDA	actual aircraft airspeed, knots
SPDA	rate of change of SPDA with respect to time
SPDKNOB	control-panel, speed-select knob setting
SPDM	status of autothrottle mode, either off or on
SPDP	speed shown on control-panel CRT display
TF	navigational radio to/from ambiguity indicator
TH	throttle movement commanded by autothrottle
$\dot{\mathrm{TH}}$	throttle rate
THROTTLE	throttle input to engine math-model equations

TIMEB	value in timer B, sec
TIMEL	value in timer L, sec
TLP	cockpit throttle level position
WCA	wind-correction angle, deg (positive to right)
WD	Direction that wind is from, deg
WS	wind speed, knots

Symbols:

h	airplane altitude, ft
$\dot{h}$	altitude rate, ft/min
V	airplane velocity, ft/sec
ψ	airplane heading, deg, magnetic

DESIGN GOALS AND REQUIREMENTS

The ATAS concept is designed to manage the aircraft autopilot and navigation radios for the pilot during an instrument approach from terminal area entry through the missed approach. The ATAS performs this management task on the basis of stored instrument approach data for each approach to be flown. The purpose of the ATAS concept is to improve the interface between pilot and cockpit automation and to reduce the potential for pilot error. Pilot error potential is reduced by eliminating the requirement for the pilot to continuously enter various frequencies and courses into navigational radios and to correctly position numerous autopilot controls as the approach progresses. Pilot error potential is further reduced by minimizing the probability that pilot distraction or chart misinterpretation could cause a deviation from the correct flight path.

The purpose of this particular ATAS design was to develop the software and hardware to the level where the concept could be implemented in the Langley General Aviation Simulator. This simulated ATAS could then be used to study the pilot interface with this type of system, to determine if the pilot could maintain better situational awareness with this level of automation, to compare pilot errors made while using the ATAS with errors made while using a baseline autopilot configuration, and to test the algorithms used for ATAS decision making. Failure modes were not considered, and a number of features that would be required in an FAA certified system were not developed because the ATAS was to be used in the controlled environment of a simulator. As an example, consider the instrument approach shown in figure 1. The pilot would normally be cleared for the approach after being vectored to a position and heading that would intercept the localizer at a reasonable altitude, intercept angle, and distance from the runway. It is permissible for the simulated ATAS to assume this is always true. A flight-quality ATAS, however, would take into account the possibility of being cleared for the approach when not on a proper intercept course, and would notify the pilot of the occurrence.

Standard instrument flying rules and procedures and the current ATC environment were used in the design of ATAS software algorithms. Many instrument approaches are flown in an ATC environment that provides radar vectors to the final approach course. Frequently, however, an entire instrument approach must be flown without radar assistance. When provided with radar vectors, the pilot simply maintains the headings and altitudes assigned by ATC. After receiving clearance for the approach, the pilot maintains the last assigned altitude and heading until the airplane is established on a segment of the published approach procedure. Figure 1 shows an instrument approach procedure where the pilot is normally provided with radar vectors. When not provided with radar vectors, the pilot proceeds to an initial approach fix (IAF) and executes the published approach. Figure 2 shows an approach that is typically flown without radar vectoring.

In any ATC environment, the pilot complies with a clearance to maintain a heading, track an airway, or proceed directly to a radio navaid prior to receiving approach clearance. After receiving approach clearance, the pilot maintains the last assigned altitude while establishing the aircraft on the published approach, then uses the altitudes and courses depicted on the approach chart. The ATAS concept uses these same guidelines. Prior to receiving approach clearance, the pilot instructs the ATAS to use pilot-entered headings and altitudes. After receiving approach clearance, the pilot directs the ATAS to use the data for the stored approach procedure to execute the approach. The ATAS must then maintain the last altitude, establish the aircraft on the published approach path, and complete the approach. This procedure enables the ATAS to be equally useful in radar and nonradar situations.

AIRPLANE SIMULATION

The ATAS was designed for implementation in a general aviation research flight simulator. The simulator consists of an enclosed cockpit (fig. 3) interfaced to a general-purpose digital computer. The cockpit is fully enclosed by the cabin section of a light-airplane fuselage. The simulator's instrumentation and avionics are typical of an IFR-equipped high-performance single-engine or light twin-engine airplane. This includes a horizontal-situation indicator, dual VOR receivers, ADF, and a two-axis autopilot. An array of speakers provides realistic wind and engine noise up to volumes typical of general aviation aircraft. The control yoke (elevator and ailerons) is hydraulically loaded to provide the appropriate variable force gradients. Rudder-pedal force feel is supplied with springs. This simulator has been used for related studies in automation and displays (refs. 2 and 3).

The math model for a typical high-wing, four-seat, single-engine, general aviation airplane was used in the ATAS simulation. This math model included changes in flight-control effectiveness and force gradients as a function of airspeed, wing-flap-extension effects, a landing-gear model, an atmospheric wind-turbulence model, and a radio navigation-aid data base.

The simulation navigation-aid data base (ref. 4) permits defining a real navigation environment so that a subject pilot may fly cross-country flights and instrument approaches by using standard instrument charts. This data base includes the location, Morse code audio identifier, and frequency, as applicable, of VOR, DME, NDB, marker beacon, localizer, and glide-slope transmitters.

The simulator is interfaced with a graphics computer and a visual landing display system (VLDS). The graphics computer provides the capability to simulate

advanced displays or alphanumeric data on cockpit cathode-ray tubes (CRT). The VLDS uses a 1:750 scale terrain model and a closed circuit television to provide an out-the-windshield view during approach and landing. Realistic cloud-breakout, low-visibility, and night effects can be provided.

ATAS HARDWARE

The additional simulator hardware required for the ATAS simulation consisted of a control panel located above the existing autopilot switches. (See fig. 4.) Nearly all pilot interaction with the ATAS is through this control panel. Inputs are provided by using the push buttons and knobs around the CRT, and system and approach status are displayed on the CRT.

Pilot input to the ATAS consists of an off/standby/on switch, push buttons to engage the go-around and holding pattern features, automatic and manual mode select push buttons for course and altitude guidance, heading and altitude-select knobs, and an on/off push button and speed-select knob for the autothrottle. Two push buttons were installed as spares. The functions of these controls are explained in a subsequent section. An autopilot-disengage button on the control yoke releases the solenoid-held autopilot panel switches for rapid autopilot deactivation. A software-controlled autothrottle disengage switch in the throttle quadrant deactivates the autothrottle any time the pilot moves the throttle to the idle position. Both the autopilot and autothrottle can be disengaged normally from the control panel shown in figure 4.

Figure 5 is a sketch of the ATAS display output. Areas along the left edge of the CRT show the status of the course and altitude mode (auto or manual), the pilot-selected or ATAS-selected course and altitude, the autothrottle status (off or on), and airspeed. Areas along the top of the CRT illuminate to indicate when the go-around or hold function is selected. The remaining area on the CRT displays an electronic course-deviation indicator (ECDI) and five lines of alphanumeric data. The ECDI shows the radio frequency of the station that is being used for course guidance, the ATAS-selected course to or from the station, and the course deviation. The radio frequency is shown to the right of the ECDI. The box at the center contains either a "T" or an "F" to indicate to or from and the numbers below the box show the selected course. Course deviation is indicated by a bar that grows away from the to/from box as deviation increases. The bar movement is similar to, and the sensitivity is identical to, the movement of a conventional electromechanical course-deviation indicator needle. The uppermost line of text advises the pilot of the aircraft's progress in the approach with messages such as: beginning descent, outbound to procedure turn, final approach, missed approach, and entering holding pattern. The second line of text presents the altitude deviation from decision height (DH), minimum descent altitude (MDA), or other appropriate reference altitude. The third line of text presents the calculated direction and distance to the airport. The fourth line displays the autopilot lateral and vertical mode as selected by the ATAS. Finally, the bottom line shows the name of the approach for which data are stored and the associated DH or MDA.

The ATAS control panel is located adjacent to the autopilot controls because the two are used together as one system. The ATAS-autopilot combination was then mounted in the instrument panel immediately to the right of the flight instruments (fig. 6). The autopilot controls consist of four solenoid-held rocker switches, a pitch command wheel, a roll command knob, and a mode-select switch (fig. 4). The four rocker switches engage the autopilot roll, heading, pitch, and altitude functions. The roll

feature simulates engagement of an aileron servo and allows the pilot to command bank angle with the roll knob. The heading function disables the roll knob and allows use of the mode-select knob to select heading hold, heading select, omnicoupling, or localizer coupling. Heading hold maintains the heading that existed when the mode was selected. Heading select maintains the heading defined by the pilot-selected position of the heading bug on the HSI. Omnicoupling causes the autopilot to intercept and track selected VOR radials. Localizer coupling provides the same capability for airport localizer facilities. The pitch function simulates engagement of an elevator servo and allows the pilot to command pitch angle with the pitch command wheel. The altitude function disables the pitch wheel and provides altitude hold and glide-slope coupling. Mechanical interlocks require the roll switch to be turned on prior to the heading switch. Also, the pitch switch must be on prior to turning on the altitude switch. An electrical interlock prevents the pitch channel from engaging when the roll channel is off. The autopilot panel is from a commercially available autopilot. The autopilot control laws, however, were developed locally for implementation in the simulation program (ref. 5).

The autothrottle function was implemented in software. The cockpit throttle could not be moved by the autothrottle commands because of the absence of any servos. An autothrottle term was simply added to the throttle-position term in software when the autothrottle was on.

In addition to the lack of any autothrottle servos, other hardware compromises had to be made for the simulator implementation. The ATAS concept requires that the aircraft be equipped with electronically tunable navigation radios. The ATAS tunes the radios, and the frequency in use appears on the frequency display. The simulator was equipped with radio panels with mechanical drum-type frequency displays that had to be manually tuned. It was therefore necessary for ATAS radio tuning to be simulated in software by ignoring the manually selected radio frequency. This meant that the active frequency was not necessarily the one displayed by the radio. The active frequency was therefore displayed on the ATAS CRT, as shown in the upper right corner of the ATAS display sketch (fig. 5).

PILOT OPERATION OF ATAS

The off/standby/on switch controls the state of the ATAS and its interface with other simulator systems. The relationship between the ATAS state and the various signal paths is illustrated in figure 7. When the ATAS is off there is no interface between the ATAS and the radios or throttle. The course-deviation signal shown on the HSI is provided by NAV 1, the autopilot mode is determined from the position of the autopilot mode-select switch, and the heading command for the heading-select mode comes from the HSI heading bug. When the ATAS is put in standby, the NAV 1, ADF, and DME radios, as well as the throttle, are connected to the ATAS. This enables the ATAS to tune the radios and acquire navaid data and enables the pilot to use the autothrottle function. The course-deviation signal displayed on the HSI is now provided by the ATAS and is not influenced by the omnibearing selector (OBS) setting. Autopilot mode-select and heading commands are input by the pilot as if the ATAS were off. The pilot cannot use autopilot navigation coupler modes in this ATAS state, because the course-deviation signal used by the autopilot can only be provided by NAV 1, which the pilot no longer controls. The purpose of the standby state is to permit direct autopilot use by the pilot while loading approach data into the ATAS. When the ATAS is turned on, the autopilot is connected to the ATAS by the mode-select and the heading command signal. In this state, the heading bug on the HSI and the autopilot mode-select switch are inoperative. The pilot uses the autopilot

solenoid-held switches to select which channels (pitch and heading) are operative and uses the ATAS panel to control those channels.

The pilot would normally accomplish approach-data entry during a low workload period prior to actually entering the airport terminal area. For this reason, it was decided not to construct the hardware necessary to simulate approach-data storage. An ATAS designed for flight use would require some means for the pilot to enter approach data or select data from a mass storage device.

When the ATAS is turned on, the course and altitude features are activated in manual mode at the actual heading and altitude. If the autopilot heading channel is off, then the indicated course on the ATAS display tracks the airplane heading, and movement of the course knob has no effect. If the autopilot heading channel is on, then the indicated course on the ATAS display is the airplane heading at the moment the ATAS was switched on, the course knob can be used to dial in new headings, and the ATAS commands the autopilot to follow the indicated heading. The ATAS altitude feature follows the same rules as the course feature for altitude initialization and autopilot interaction. At the moment that both the ATAS on status and autopilot altitude channel on status become true, the aircraft altitude is latched into the ATAS display and held by the autopilot. The pilot may then dial new altitudes with the ATAS altitude knob, and the aircraft goes to that new altitude.

When the course and altitude functions are in the manual mode, the airplane maintains pilot-commanded headings and altitudes. The pilot toggles course and altitude between manual and automatic with the mode-select push buttons. The automatic mode commands the ATAS to use the stored approach data and internal logic to complete the approach. The pilot may put the course function in automatic, provided the autopilot heading channel is on and the approach data have been stored. The altitude function may be placed in automatic, provided the course function is in automatic and the autopilot altitude channel is on. If the pilot attempts to place either function in automatic when the required conditions are false, then no action or warnings take place. If the course function is toggled from automatic to manual, then the altitude function also reverts to manual. This software interlock between the course and altitude is designed to prevent undesired climbs or descents while the aircraft is being vectored near or across published approach segments.

The internal logic of the course function, once activated, establishes the aircraft on the published approach path, then completes the approach. The method used to establish the aircraft on the approach path depends on the approach. In the nonprecision approach of figure 2, the ATAS proceeds directly to the NDB from the point where the automatic course was selected. In the precision approach of figure 1, aircraft are normally given radar vectors to intercept the instrument landing system (ILS) localizer. On rare occasions, a pilot might use one of the published routes from Harcum, Cape Charles, or Franklin VORTAC's. The ATAS is designed to fly the published routes to the localizer if the aircraft is within 3 n.mi. of Harcum or either of the initial approach fixes (IAF) when automatic course is selected. Otherwise, when automatic course is selected, the ATAS assumes that the aircraft is being radar-vectored and that the last pilot-entered heading is the vector that intercepts the localizer. Once established on the published approach path, the course logic completes the approach as depicted on the approach chart, regardless of the type of approach.

The internal logic of the altitude function operates independently of the type of approach being executed. When automatic altitude is selected, the altitude of the aircraft is maintained if the aircraft is not on any portion of the published

approach, and the published altitudes are flown if the aircraft is established on the published approach. The criterion for determining whether the aircraft is established on course is defined in the appendix flowcharts.

The go-around button above the CRT can be used to instruct the ATAS to discontinue descent while on the final approach course. Pressing this button while on final approach illuminates an annunciator on the CRT (fig. 5) and stops the aircraft descent. The aircraft then proceeds to the missed approach point and executes the missed approach procedure. Pressing the go-around button while not on final approach produces no effect.

The hold button is used to instruct the ATAS to enter the next published holding pattern along the aircraft flight path. When this mode is armed, an annunciation illuminates on the CRT. Pressing the button when the mode is armed turns the mode off and inhibits holding-pattern entry.

The autothrottle is activated by pressing the on/off button and dialing in the desired airspeed in knots. At the moment that the autothrottle is activated, the indicated desired airspeed is identical to the actual airspeed of the aircraft. This prevents any throttle transients upon activation. The autothrottle can be shut off by pressing the on/off switch again, by turning the ATAS off, or by manually moving the throttle lever to the idle position.

Both the hold mode and the autothrottle are automatically switched on by the ATAS at the beginning of a missed approach. This enables the ATAS to enter the missed approach holding pattern without further pilot input and prevents the aircraft from slowing to a dangerously low airspeed as the climb is begun. The pilot can turn the modes off again if desired.

ATAS SOFTWARE

The major software functions are interpreting pilot inputs, scanning the airplane navigation radio indications, tracking the airplane progress in the approach, providing messages to the pilot, and commanding the appropriate autopilot modes. The ATAS software was integrated with the airplane simulation math-model software as a subroutine. The ATAS software flowcharts are presented and discussed in the appendix.

The operation of the ATAS is based on defining the approach as a series of segments. The ATAS can determine which segment the airplane is on and can sequence from one segment to the next. Each segment has associated with it a set of criteria for determining when that segment should be used and a list of parameters to set for that segment. Examples of segment parameters to be set include segment heading/course, altitude, radio frequencies, autopilot modes, and messages to be displayed to the pilot. The segment criteria and parameters comply with the criteria set forth in reference 6 for the design of instrument approach procedures. For simulation purposes, the segment data were stored in the form of subroutines that test for the required criteria and set the parameters. This method of data storage allowed quick simulator implementation of ATAS, but would not be suitable for a production ATAS.

The ATAS software was written only for use with two instrument approaches in a structured simulation scenario. As a result, some modifications would be required to add additional approaches or to use the software in a flight environment.

Wind compensation routines were written for use in holding patterns. These routines use holding-pattern inbound leg time and wind correction angle to adjust the outbound leg time and heading. Wind compensation routines for other flight segments, such as procedure turn execution, were not developed for this effort.

CONCLUDING REMARKS

An automatic terminal approach system (ATAS) concept was developed and implemented in the Langley General Aviation Simulator to facilitate studies of ways to improve the pilot-machine interface.

During implementation, numerous instrument approaches were flown to verify proper operation of the ATAS. The ATAS performed the approaches properly and is considered ready for use.

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APPENDIX

ATAS PROGRAM FLOWCHARTS

Overview

The ATAS program is called by the simulation math-model program at the simulation iteration rate of 32 times per second. The ATAS software consists of a short main program and numerous other routines that perform specific functions. The data for each of the instrument approaches to be flown are stored in the form of subroutines NAV and SEARCH. This data representation allows quick simulator implementation of the research system. Only the data subroutines written for the Wakefield NDB approach (fig. 2), are presented here.

The main ATAS program flowchart is shown in figure 8. The first routine, called DISPLAY, provides for all pilot-ATAS interaction through the control panel and CRT display. The routines NAV and SEARCH are called only if they have been stored. If the ATAS is on, then the course mode and the altitude mode are either automatic or manual, depending on whether the pilot wants approach data or pilot-input parameters to be used for autopilot control. If the ATAS is not on, then the course and altitude functions are inoperative, and autopilot control is given to the pilot. Finally, AUTOPILOT and AUTOTHROTTLE are called to actually control the autopilot and calculate throttle commands to hold the selected speed.

Pilot Interface Routines

Figure 9 shows the flowchart for subroutine DISPLAY. The ATAS is either at on, standby, or off, as set on the appropriate control-panel switch. System initialization is performed when the switch is at off or standby. If the ATAS is off, then the autothrottle is shut off, the direction and distance to the airport are initialized, and the CRT display is shut off. The logic used by subroutine DISPLAY when the ATAS is on is shown in figure 10. First, the autothrottle on/off button is read. If the autothrottle is not on, a test of SPDFLAG is made to determine whether the autothrottle should be turned on. The flag SPDFLAG is set on the first program iteration when beginning a missed approach to activate the autothrottle. The variable SPDP is the displayed speed and is either set to the value of the speed-select knob (SPDKNOB) or the airspeed of the airplane, depending on the autothrottle status. The variable SPDP becomes the commanded airspeed when the autothrottle is on. When the autothrottle is off, the position of SPDKNOB is defined to be equivalent to the speed of the airplane to prevent throttle transients upon autothrottle activation.

The course mode push button is read next, and, if the criteria for permitting the mode to be automatic are not met, the course mode is forced to manual. The heading to be displayed on the ATAS panel (HP) is set by the course-select knob, by the heading supplied by approach data (HD), or by the actual heading of the airplane (HA), depending on whether the course mode is manual or automatic and whether the autopilot is on or off. Defining the position of the course-select knob to be equivalent to HP prevents any transients upon selecting the manual course mode.

The altitude mode push button is read next. The altitude mode logic is similar to the course mode logic. When the altitude mode is automatic and the altitude provided by approach data (ALTS) is -888 or -999, the data are commanding altitude hold

or glide-slope vertical modes, respectively. In this case, the position read from the altitude-select knob is continuously defined as equivalent to the altitude of the airplane.

The go-around push button is read next if the airplane is on final approach (indicated by a segment number of 1). If the airplane is not on final approach, the go-around flag (GRND) is cleared. The go-around flag is used in another routine to put the autopilot in the altitude hold mode.

The reading of the hold push button is the last reading of the ATAS controls. The hold push button can set and clear the flag HOLD. This flag is used elsewhere in the program to access the holding-pattern data and logic. The flag HOLDFLAG is set on the first iteration of a missed approach to automatically enable holding-pattern entry.

The next sections of the flowchart show the status of go-around, hold, course mode, altitude mode, and autothrottle. The heading, altitude, and speed values (HP, ALTP, and SPDP) are also displayed. The letters HOLD or GS are substituted for ALTP if ALTP indicates that the altitude hold or glide-slope tracking is engaged. The electronic course-deviation indicator (ECDI) is displayed if the autopilot is navigation-coupled or if a procedure turn or holding pattern are being flown. A procedure turn is indicated by a segment number (integer) from 50 to 59, and a holding pattern is indicated by a segment number (integer) greater than 59.

The remainder of the ATAS-on routine places the appropriate alphanumeric messages on the remaining five lines of the CRT. Line 1 displays a steady or flashing message as specified by the variables MSG and MSGF. These two variables are set by the approach-segment data. The list of messages that may be displayed are shown in table I. The flashing messages are shown for 5 seconds and are then cleared. The data may specify both a flashing and steady message. In this case, the flashing message is first shown for 5 seconds, and then the steady message is displayed. Line 2 displays the relationship between airplane altitude and decision height (DH), minimum descent altitude (MDA), or other reference altitude as appropriate. When on a final approach, DH is appropriate if a glide slope is being used, and MDA is appropriate if no glide slope is in use. When on a final approach, the words "AT DH" or "AT MDA" are used when the airplane is within 1 ft below or 5 ft above DH or MDA. When not on final approach, line 2 is blanked if the airplane is within 20 ft of the reference altitude. Line 3 displays the distance and direction to the airport as determined by subroutine NAV. This portion of DISPLAY was written to handle only the two approaches to be simulated. Therefore "TO PHF" or "TO AKQ" is shown depending on the stored data. Line 4 displays the autopilot lateral and vertical mode or informs that the autopilot is off. Finally, line 5 indicates what approach data, if any, have been stored.

Figure 11 shows the initialization subroutine called by DISPLAY when the ATAS is off or in the standby mode. The various flags used by the ATAS are cleared, and the display message numbers, segment numbers, holding-pattern wind-correction angle, and autopilot radio request number are set to zero. The segment number (SN) and last segment number (LSN) must be set to zero to prevent errors in the SEARCH routine. The autopilot radio request number (RT) must be set to zero when the autopilot is not in a navigation-coupled mode to enable the subroutine NAV to have access to all radios. The variable HPTIME is the time, in seconds, required for the outbound leg of a holding pattern. Here it is initialized to the no-wind value of 60. Finally, the course and altitude modes are set to manual, and the heading and altitude variables are set to the actual heading and altitude of the airplane.

Figure 12 shows the logic called by subroutine DISPLAY when the ATAS is in the standby mode. This routine is a subset of the logic used when the ATAS is on. Only the autothrottle controls are active, and only the autothrottle status, distance and direction to the airport, and approach-data stored information are displayed.

Approach-Data Routines

The data subroutine NAV written for the Wakefield NDB approach is shown in figure 13. This routine scans the navaids in the terminal area and then determines the direction and distance to various points. The flag NAVR and the variables RN and FREQC are set by subroutine NAV and are used by subroutine RADIO to tune the appropriate navigation receiver. The flag NAVR informs subroutine RADIO that it has been called by subroutine NAV and that this tuning request has a lower priority than a request to time a radio for autopilot navigation coupling. The variable RN specifies which radio receiver is being requested. The values 1, 2, 3, and 4 specify NAV 1, NAV 2, ADF, and DME, respectively. The frequency that the radio RN should be tuned to is specified by FREQC. The Wakefield NAV subroutine first tunes the ADF receiver to the Wakefield NDB and reads the relative bearing to the station. This bearing and the airplane heading are used to determine the radial the airplane is on. All calculated bearings and directions are adjusted to be in the interval from 0° to 360°. After ADF tuning, the DME and NAV 2 are tuned to Franklin (FKN) and Hopewell (HPW) VORTAC's for distance and bearing information. After all radio tuning and reading is complete, the distance to the airport (DISTA) and the distance to Swing intersection (DISTS) are calculated from their distance and direction from FKN and the airplane distance and direction from FKN. Since the NDB is located on the airport, the direction to the airport is calculated as the reciprocal of the radial from the NDB. Finally, the flag NAVR is cleared before returning to the main program.

The data subroutine SEARCH for the Wakefield NDB approach is shown in figure 14. This subroutine tests the criteria for each approach segment and, when a segment tests true, sets up the data for that segment. Examples of test criteria include the last segment number, course deviations, distances, and times. The last segment number (LSN) is used to enforce the proper sequence of segments. The final approach segment, for example, can only become true while on a procedure turn segment. The order of segment testing is important for correct decisions. Inspection of the approach segmentation diagram (fig. 15) and the SEARCH flowcharts (fig. 14) reveal, for example, that segments 7, 8, and 9 will never be detected unless those tests occur before the test for segment 3.

Examples of the data set up for each segment include segment heading (HS), radio frequency for autopilot navigation coupling (FREQC), autopilot mode, and segment altitude (ALTS). Because the autopilot always turns in the shortest direction to a commanded heading in the heading select mode, all turns approaching 180° are defined as two segments, each of which requires a turn of about 90°. This ensures that the turn will be in the proper direction.

Subroutine SEARCH begins by storing the minimum descent altitude for the approach into the variable MDA (fig. 14). This altitude is used by subroutine DISPLAY to calculate the difference between airplane altitude and MDA on final approach. Next, the criteria for segment 1 are tested. The airplane switches to segment 1 if LSN = 52 (the procedure turn) and the airplane is within 10° of the final approach course (DIRA within 10° of 200°). The segment 1 test is also true if the airplane is on final approach (LSN = 1) and if either the course deviation is less than or equal to 10° or the airplane is within 1.2 n.mi. of the final approach

course. The status of the to-from ambiguity indicator (TF) is checked to prevent segment 1 from testing true after NDB station passage. The tests for each of the remaining segments are similarly performed. Some of the segment tests are based solely on the last segment number and one other condition, such as a time, heading, or altitude. For example, the procedure turn (segment 50) begins when the airplane has been outbound from the NDB (segment 2) for 2 minutes, and the turn into the missed-approach holding pattern (segment 5) begins when the airplane has reached an altitude of 1500 ft during climbout (segment 4). Once a segment tests true, the remaining segment tests are skipped. If no segment tests are true, a test is made to see if the ATAS has become lost. The lost test is true if the course mode is automatic and no segment tests true for 2 minutes when the airplane has previously been tracking a segment. A warning message is displayed to the pilot if the ATAS becomes lost.

Once a segment test becomes true, a test is made to determine if the airplane is at the holding fix (the Wakefield NDB) with the hold status true. When this situation occurs, the subroutine HPENT is called to determine the proper holding-pattern entry maneuver. The airplane is at the holding fix if segment tests true and if the last segment is any of the segments leading to the fix. If the situation requiring HPENT to be called is false, then another test is made to see if the airplane is in the holding pattern. If in the pattern, and if the hold status is true, then HPCRAB is called to calculate appropriate wind-correction angles. If the airplane is in the holding pattern and the hold status is false, the remainder of the holding pattern (to the NDB) is flown. At this point, segment 2 becomes the active segment. The last action taken by SEARCH before returning to the main program is to use the segment heading (HS) provided by data to provide the command heading (HC) for the autopilot.

The data routines for each segment are shown in figure 16. These routines typically set up such parameters as the segment number (SN), the heading or course to be displayed on the CRT (HD), the segment heading (HS), the omnibearing-select value (OBS), the radio required for autopilot coupling (RT), the frequency to use on that radio (FREQC), the segment altitude (ALTS), the autopilot mode (APRL), and the message number (MSG). Many of the data routines set some other parameters. The segment 1 data routine, for example, tests the airplane heading (HA) to determine when HA is within 25° of the final approach course. This routine is first entered as the airplane is flying the procedure turn and intercepting final approach. The segment altitude remains 2000 ft until HA is nearly aligned with the final course; ALTS then becomes 840 ft, a flashing message (MSGF) is specified, and AFLAG is set. This routine is designed to specify MSGF only on the first pass after reaching the appropriate heading, so that MSGF can be cleared by subroutine DISPLAY. The segment 2 routine has the additional task of initializing and starting a timer. The timer is used by subroutine SEARCH to determine when the procedure turn should be initiated. The timer is started only when the airplane heading is within 30° of the outbound course. This prevents beginning the procedure turn too soon when segment 2 is intercepted at large angles. Segment 3 is designed to be flown from anywhere in the terminal area direct to the NDB. For this reason, the direction to the airport (DIRA) is used as the segment heading and course. The data for segment 4 (the missed-approach initial climb) sets two flags, SPDFLAG and HOLDFLAG, the first time the data are called. These flags are then used by subroutine DISPLAY to activate the autothrottle and to allow holding-pattern entry.

Segment 6 returns the airplane to the NDB after a missed approach (fig. 15) in preparation for entering the holding pattern. At selection of segment 6, the airplane is in a turn towards the NDB with the autopilot in the heading-select mode.

The segment 6 data maintain this state until the relative bearing of the NDB is greater than 355°. At this point, the airplane heading is within 5° of directly towards the NDB, the direction to the airport is used for the segment heading and course, and the autopilot mode is changed to ADF track.

The data for the holding-pattern segments (segments 60, 61, 62, and 63) must set the segment altitude based on whether the holding pattern is entered from a missed approach or from initial approach to the airport. If entered from a missed approach, an altitude of 2000 ft is maintained. If not entered from the missed approach, the altitude-hold mode is used to maintain whatever altitude existed at entry. The flag AFLAG is used to determine if entry is from a missed approach. The data routine for the outbound leg (segment 62) has the additional tasks of determining the length of time that the outbound leg should be flown (HPTIME) and of starting the timer when abeam the NDB. The outbound-leg flying time is based on airplane speed, the segment heading, and the wind velocity vector, and would be 60 seconds in a no-wind situation.

The data for the remaining segments combine the features of the segment data described above. Examination of figures 2 and 15 should explain each of the remaining segment-data routines.

Lateral and Vertical Control

Figure 17 shows the automatic lateral control logic called by the main program when the course mode is automatic. This subroutine sets up the navigation receivers for autopilot tracking and sets the autopilot lateral modes under certain conditions. If the airplane is not on any published approach segment, indicated by a segment number of zero, the autopilot is commanded to hold the heading that was displayed on the CRT when the automatic course mode was selected. The flag HFLAG is set to indicate that this heading has been latched. When the segment number is other than zero, the required heading and autopilot variables are set by the approach data, and this routine needs only to call subroutine RADIO to retune the radios for the autopilot if the segment number has changed. The lateral control logic used when the course mode is manual is also shown in figure 17. This subroutine clears various parameters, sets the commanded heading to the value dialed in by the pilot, and sets the autopilot mode request to heading select.

The automatic vertical control logic called when the altitude mode is automatic is shown in figure 18. This subroutine is used to set up the appropriate autopilot vertical mode request. The possible modes are altitude hold, altitude select, and glide slope. When the segment number is zero, or when the approach data has set ALTS to -888, the altitude-hold mode is used. The approach data specifies glide-slope tracking by setting ALTS to -999. In this case, altitude hold is used until the airplane is nearly on the glide-slope centerline, where the glide-slope mode is used. If neither altitude-hold nor glide-slope modes have been specified, the subroutine checks to see if a holding pattern has been entered prior to flying the approach. A segment number from 60 to 99 indicates a holding pattern, and the flag AFLAG determines whether the approach has been flown. This flag is set on final approach. If this holding-pattern test is false, the ALTS set by data is used as the commanded altitude, and the altitude-select autopilot mode is requested. Finally, the status of the go-around mode is tested and, if true, the altitude-hold mode is requested. The vertical control logic used when the altitude mode is manual is also shown in figure 18. This subroutine uses the pilot-entered altitude as the commanded altitude and requests the altitude-select mode of the autopilot.

APPENDIX

Autopilot and Radio Interfaces

Subroutine AUTOPILOT is shown in figure 19. This subroutine sets the autopilot lateral and vertical modes based on the mode requests provided previously. The commanded heading provided by the lateral control logic is used to overwrite the value of the position of the directional gyro heading bug. If the ATAS is not on, control of the autopilot modes is given to the pilot. Figure 19 also shows subroutine AUTOTHROTTLE. This subroutine computes a throttle movement rate as a function of speed error and speed rate. This rate is then integrated by dividing by the program iteration rate of 32 times per second and adding the result to the variable TH. The variable TH is then added to the value of the physical position of the cockpit throttle lever (TLP) to determine the throttle input to the engine math model. When the autothrottle is off, TH is set to zero. This method of autothrottle implementation was used because there were no servos to drive the throttle lever.

Subroutine RADIO is shown in figure 20. This subroutine is called by subroutine NAV and by the automatic lateral control logic of figure 17. Subroutine RADIO uses the requested radio number (RN or RT) and the commanded frequency (FREQC) to tune the airplane navigation receivers. If RADIO has been called to tune a radio for autopilot tracking, the flag NAVR is false and RT specifies the radio to be used. If RADIO has been called by NAV, NAVR is set and RN specifies the radio to be used. Autopilot requests have the higher priority. Requests by NAV are checked prior to radio tuning to assure that a radio coupled to the autopilot is not retuned.

Holding-Pattern Routines

The subroutines used to select holding-pattern entries (HPENT) and to determine holding-pattern wind-correction angles (HPCRAB) are shown in figure 21. The subroutine HPENT determines whether a direct, parallel, or teardrop holding-pattern entry should be used. The entry selection is a function of the airplane heading and the holding-pattern inbound course as recommended by the Federal Aviation Administration (FAA) in reference 7. Figure 22 shows a holding-pattern diagram and the entry criteria. In the data base, the direct entry is always assigned segment number 61, the parallel entry is assigned segment number 80, and the teardrop entry is assigned segment number 83. (See fig. 15.) The subroutine HPCRAB determines the wind correction for the outbound leg of a holding pattern as a function of the wind-correction angle required to track the inbound leg. This method is analogous to the method a pilot uses to determine the outbound wind-correction angle. For simplicity of simulator implementation, the inbound wind-correction angle is computed as a function of wind speed, wind direction, airplane speed, and inbound course. This angle is determined on each inbound leg (Segment number = 60). On each outbound leg (Segment number = 62), the segment heading provided by data is adjusted to correct for wind drift.

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2. Bergeron, Hugh P.: Single Pilot IFR Autopilot Complexity/Benefit Tradeoff Study. AIAA Paper 80-1869, Aug. 1980.

3. Adams, James J.: Simulator Study of a Pictorial Display for General Aviation Instrument Flight. NASA TP-1963, 1982.

4. Bergeron, Hugh P.; Haynie, Alix T.; and McDede, James B.: Development of a Computer Program Data Base of a Navigational Aid Environment for Simulated IFR Flight and Landing Studies. NASA TM-80064, 1980.

5. McRee, Griffith J.: Autopilot Design for General Aviation Simulator. Contract NAS1-14193, Old Dominion Univ. Res. Found., 1980. (Available as NASA CR-165900.)

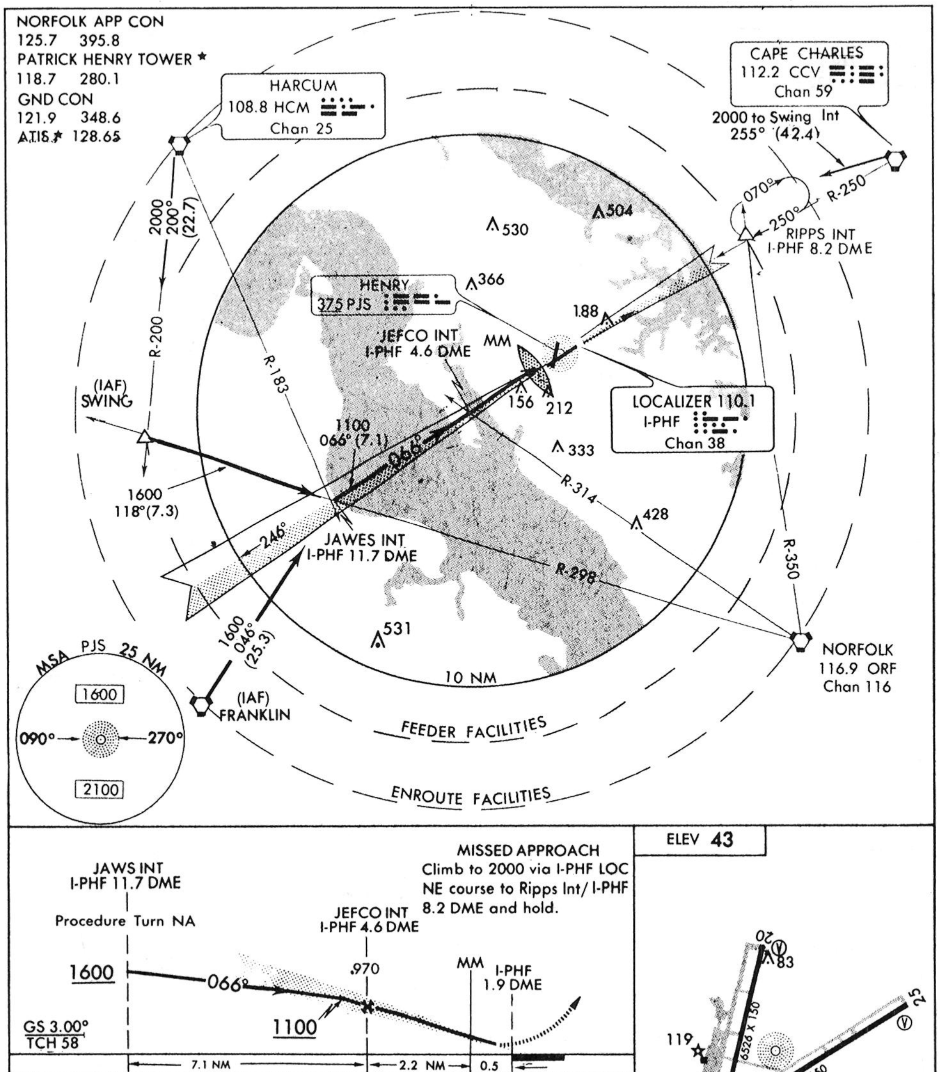
6. United States Standard for Terminal Instrument Procedures (TERPS), Third ed. FAA Handbook 8260.3B, July 7, 1976.

7. Airman's Information Manual - Basic Flight Information and ATC Procedures. FAA, Aug. 4, 1983.

TABLE I.- MESSAGES DISPLAYED ON CRT LINE 1 AND VALUES OF MSG AND MSGF USED TO SPECIFY MESSAGE

MSG value	Displayed message
0	Blank line
1	PROCEDURE TURN
2	FINAL APPROACH
3	MISSED APPROACH
4	OUTBOUND TO P.T.
5	H.P. INBOUND
6	H.P. OUTBOUND
7	ENTERING H.P.
8	USING VECTOR
9	FLYING TO STATION

MSGF value	Displayed flashing message
0	Blank line
1	BEGINNING CLIMB
2	BEGINNING DESCENT
3	STOP CLIMB
4	STOP DESCENT
5	INTERCEPT FINAL
6	GLIDE-SLOPE INTERCEPT
7	MISSED APPROACH



CATEGORY	A	B	C	D
S-ILS 7	240/24 200 (200-½)			
S-LOC 7	420/24 380 (400-½)			420/40 380 (400-¾)
CIRCLING	520-1 477 (500-1)		520-1½ 477 (500-1½)	600-2 557 (600-2)

Cat. D S-LOC visibility increased to RVR 5000 for inoperative MM.
When Control Tower not in operation: 1. Alternate minima not authorized. 2. SSALR becomes SSALS. 3. All categories increase S-ILS 7 visibility to RVR 4000. 4. Increase S-LOC 7 visibilities Cats. A, B and C to RVR 4000 and Cat. D to RVR 6000.

FAF to MAP 2.7 NM					
Knots	60	90	120	150	180
Min:Sec	2:42	1:48	1:21	1:05	0:54

Figure 1.- ILS approach (runway 7) at Patrick Henry International Airport.

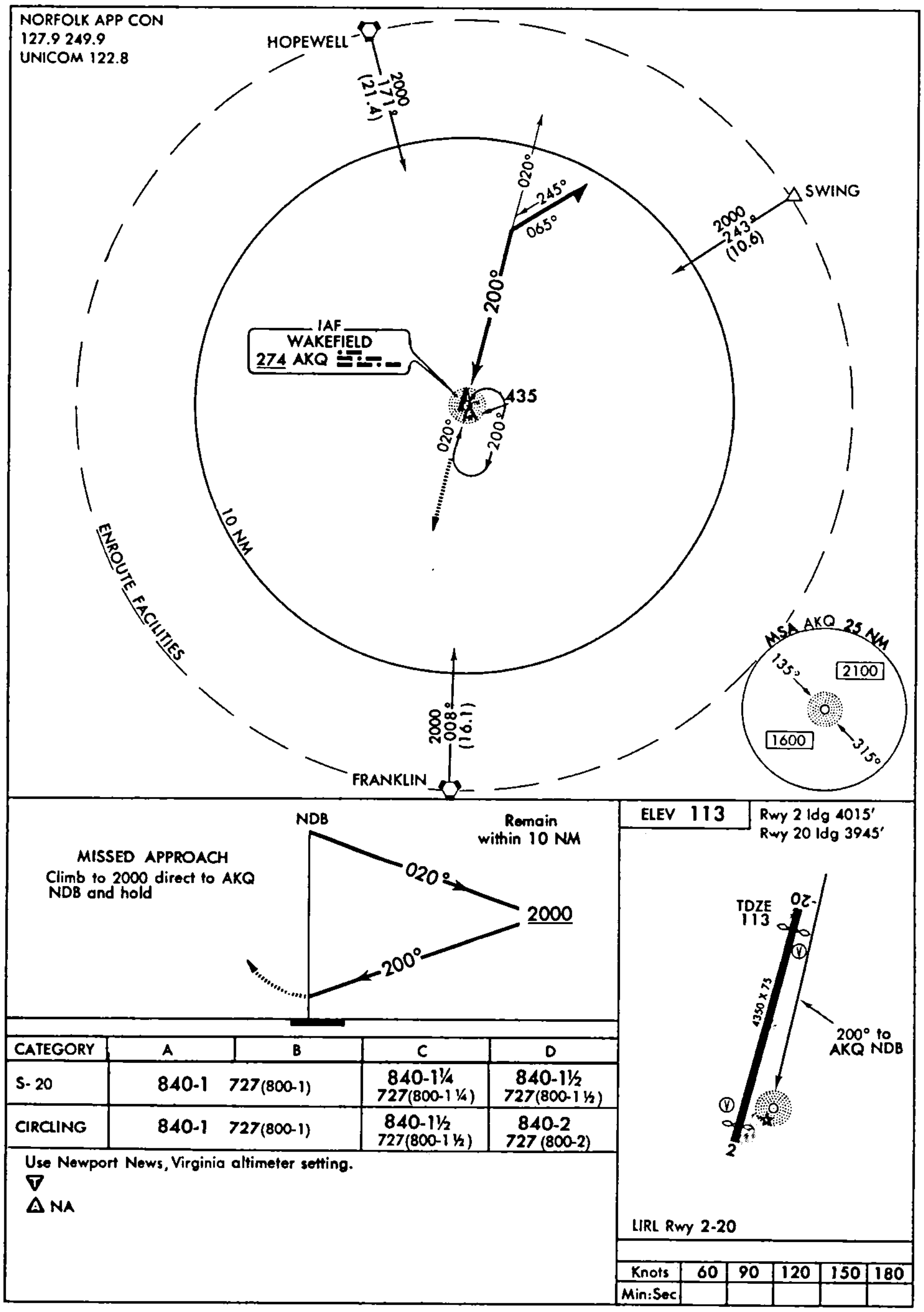
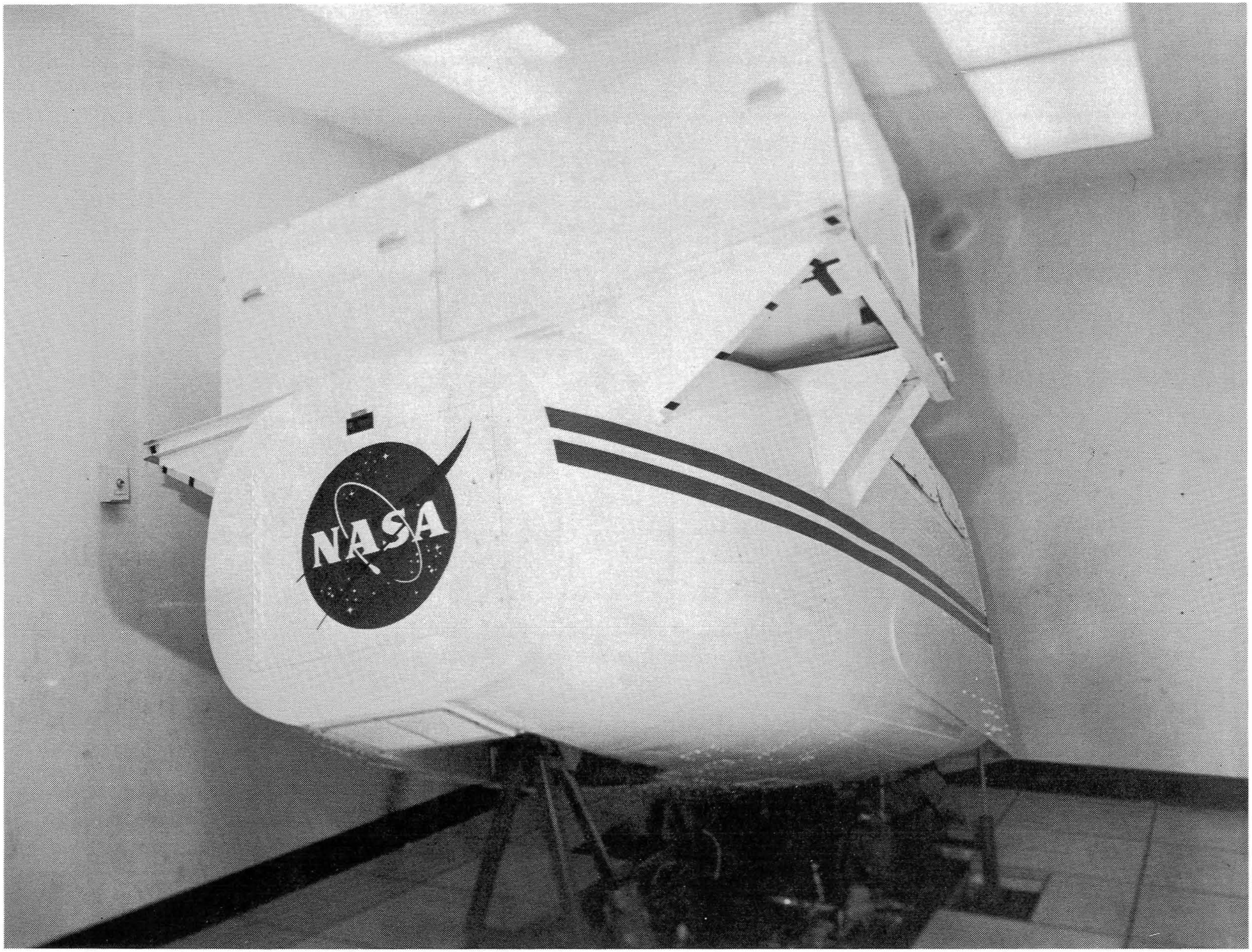
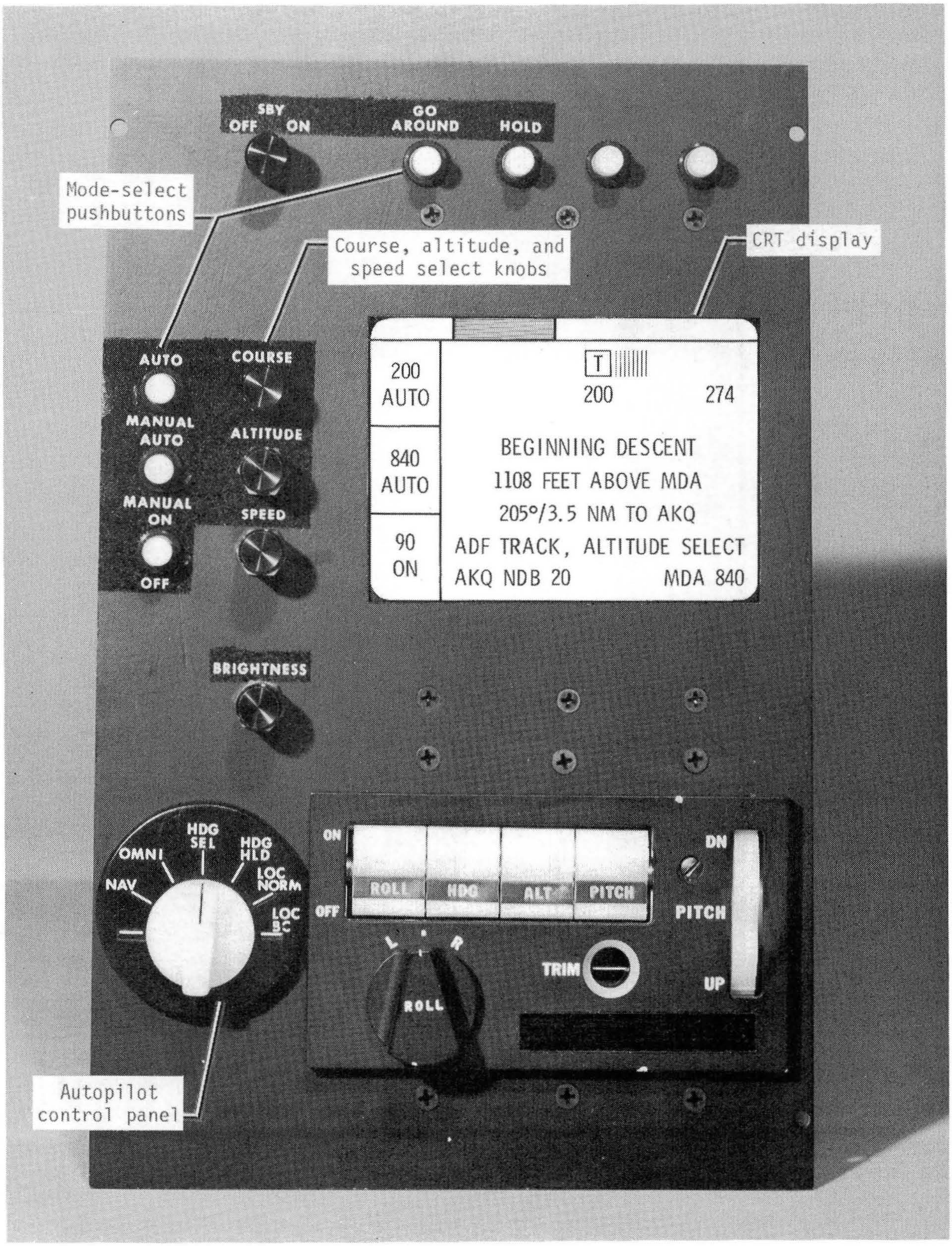


Figure 2.- Nondirectional radio beacon approach (runway 20) at Wakefield Municipal Airport.



L-75-7567

Figure 3.- External view of cabin of Langley General Aviation Simulator.



L-83-134

Figure 4.- ATAS control and display panel.

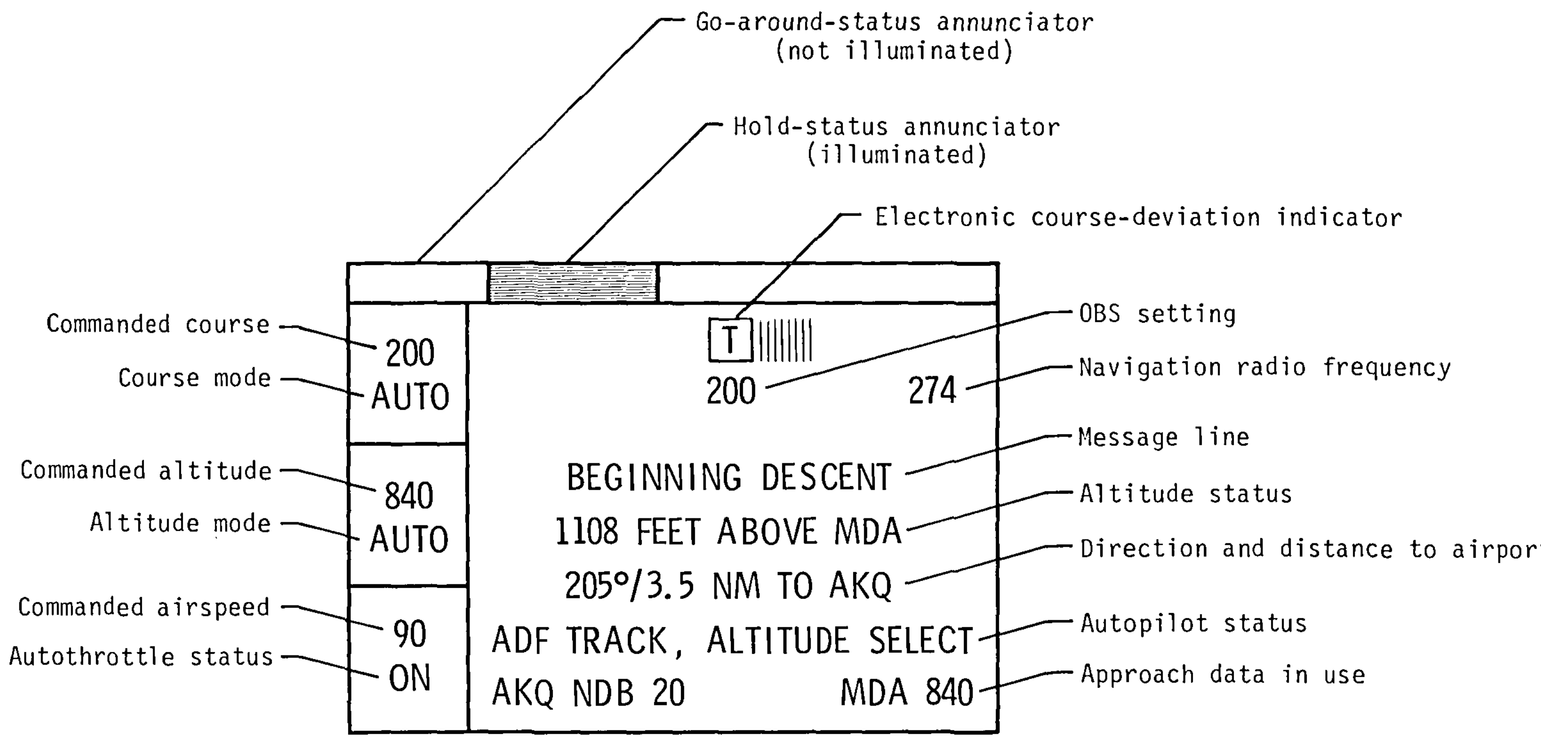
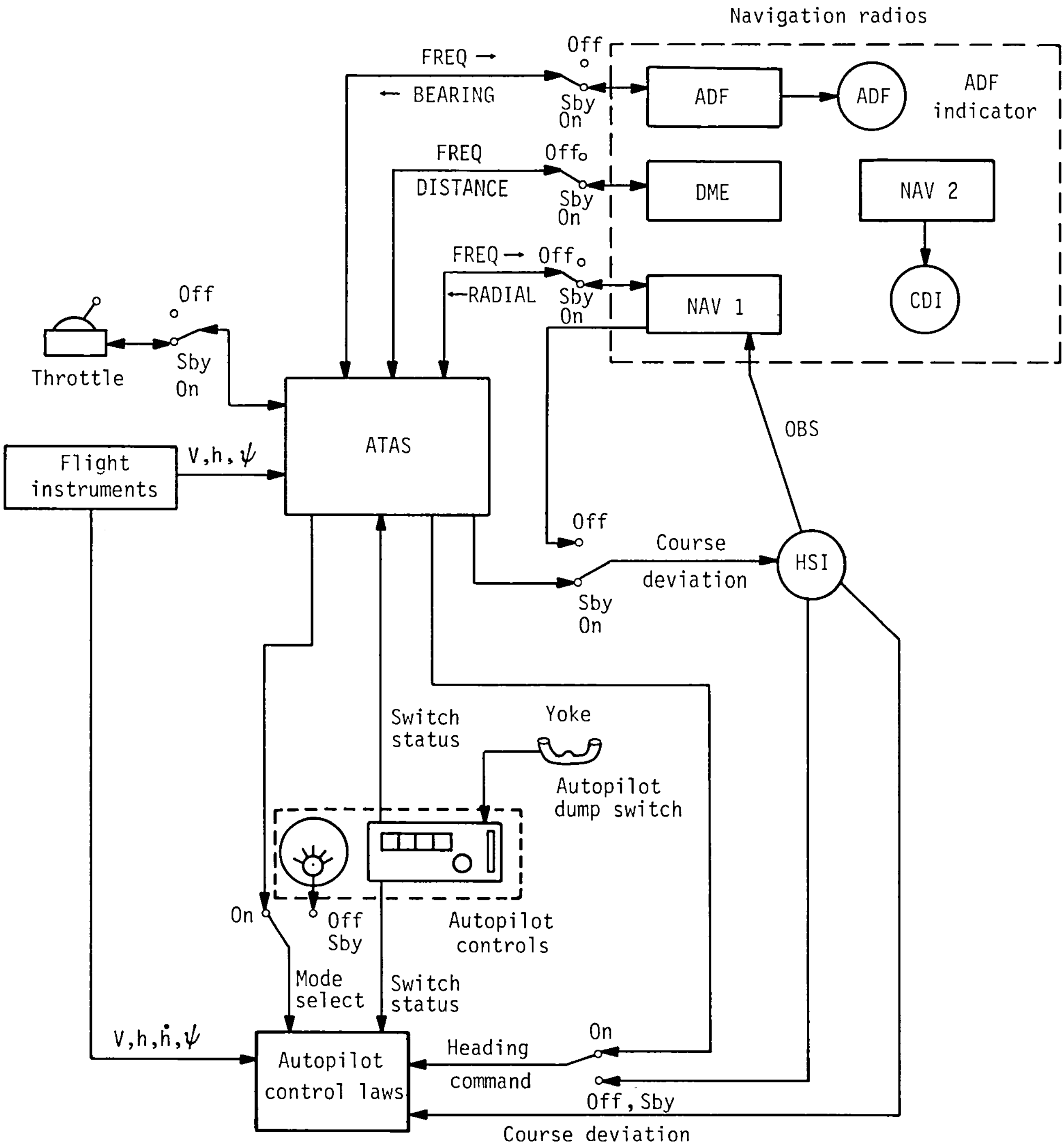


Figure 5.- Sketch of ATAS CRT display.

L-81-7651

Figure 6.- ATAS installation in Langley General Aviation Simulator.



Note: States of software switches shown are determined by position of ATAS off/standby/on switch.

Figure 7.- ATAS interface with simulated avionics and instruments.

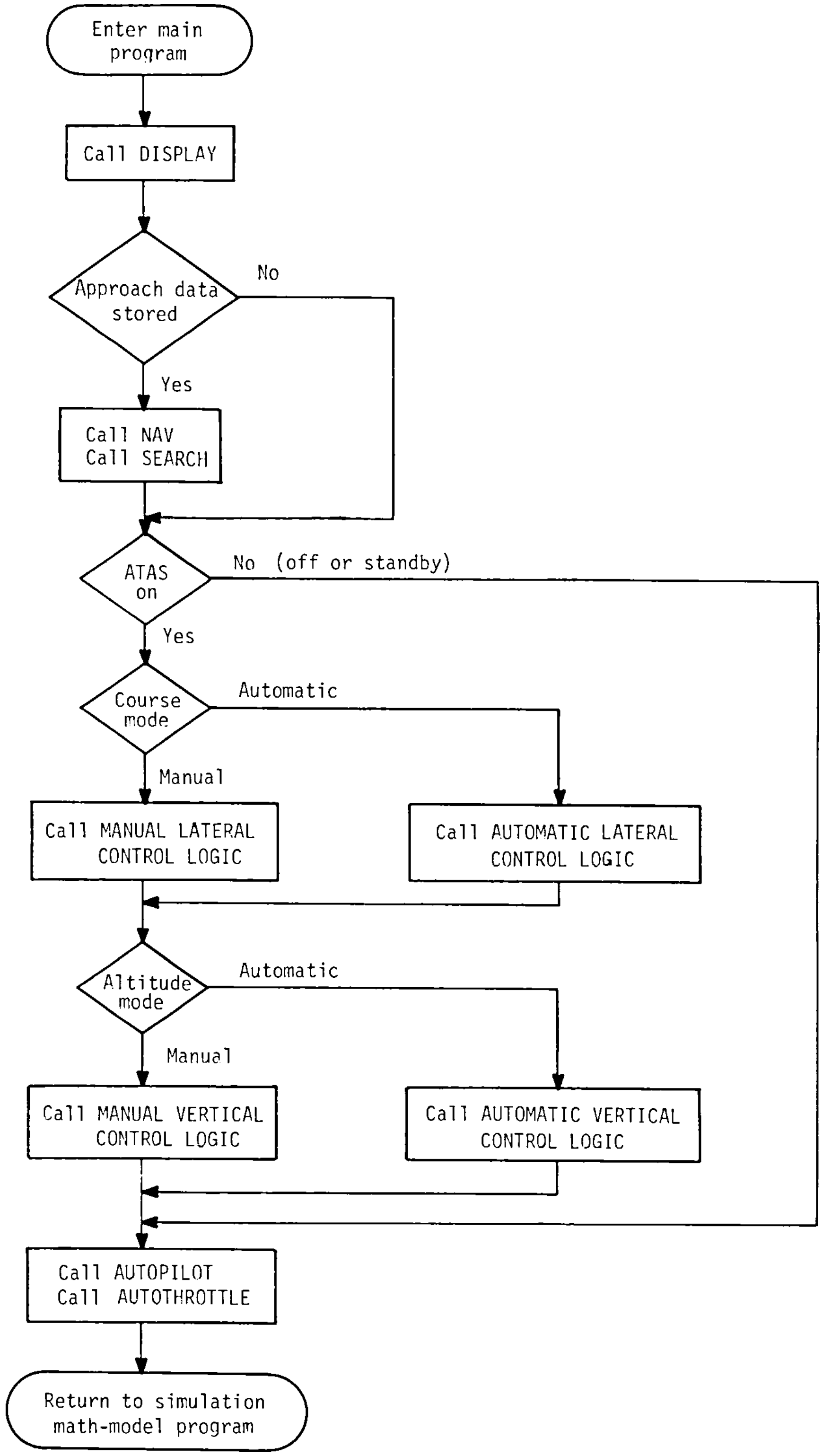


Figure 8.- Main ATAS program flowchart.

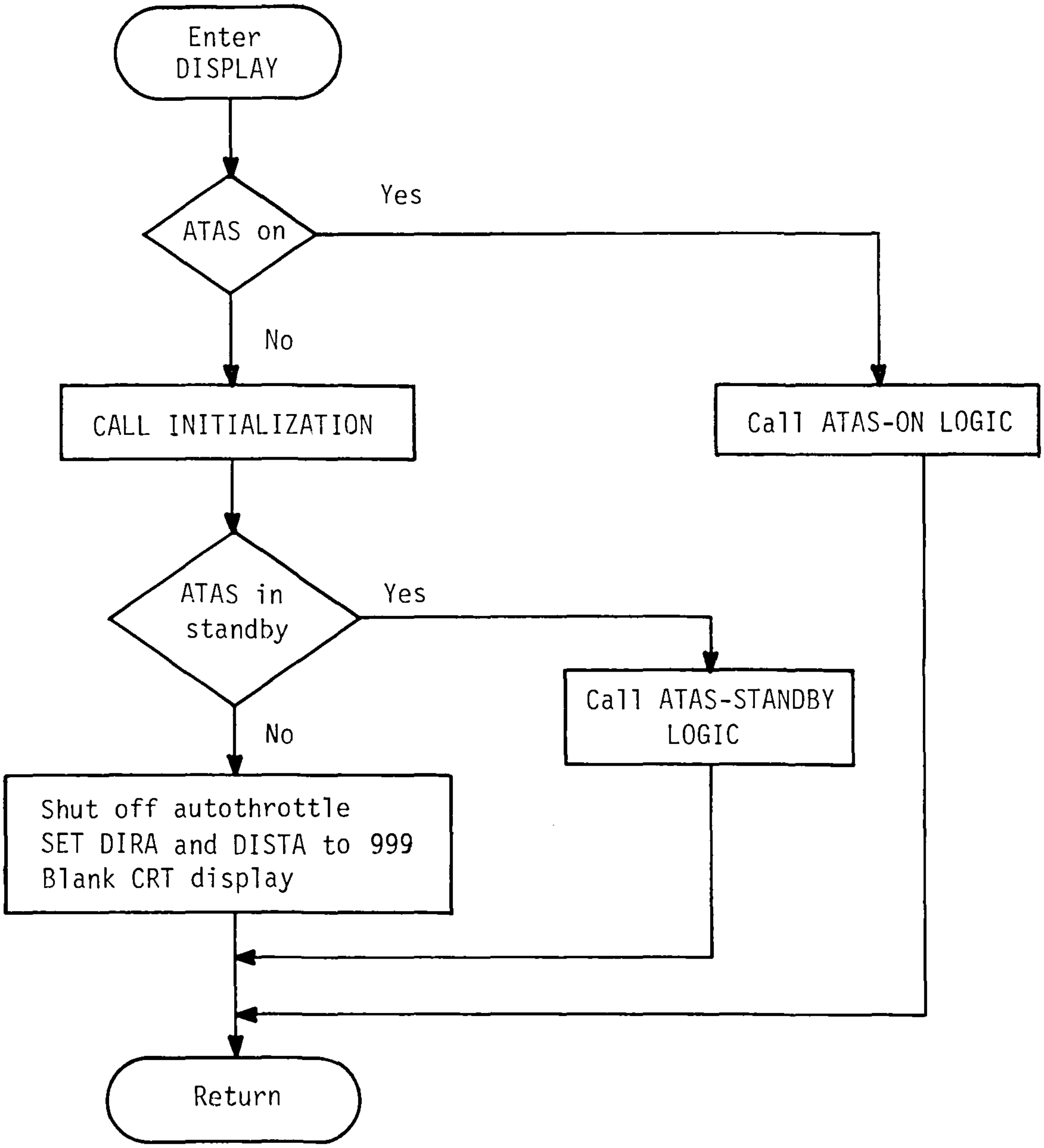


Figure 9.- Subroutine DISPLAY.

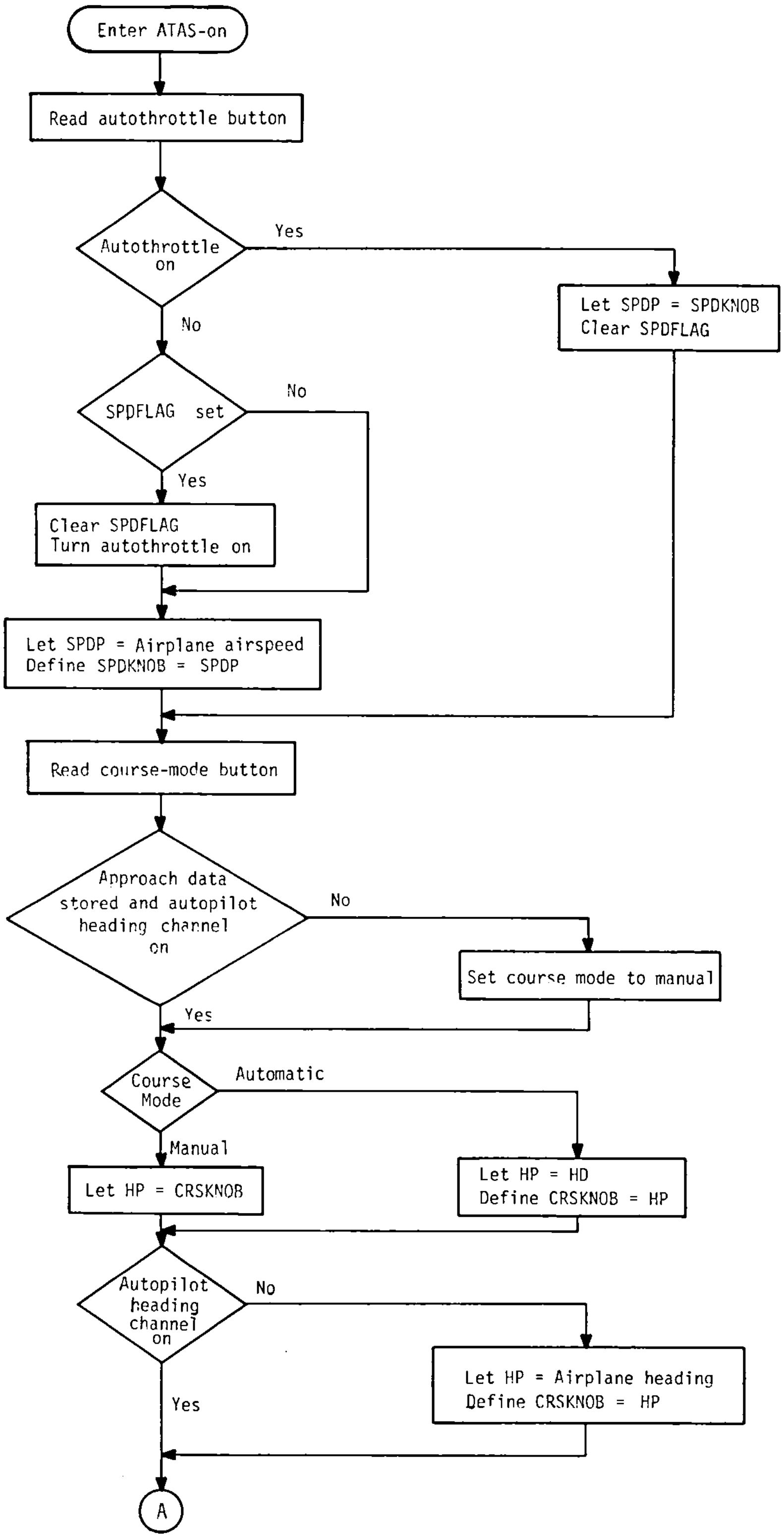


Figure 10.- ATAS-on logic for subroutine DISPLAY.

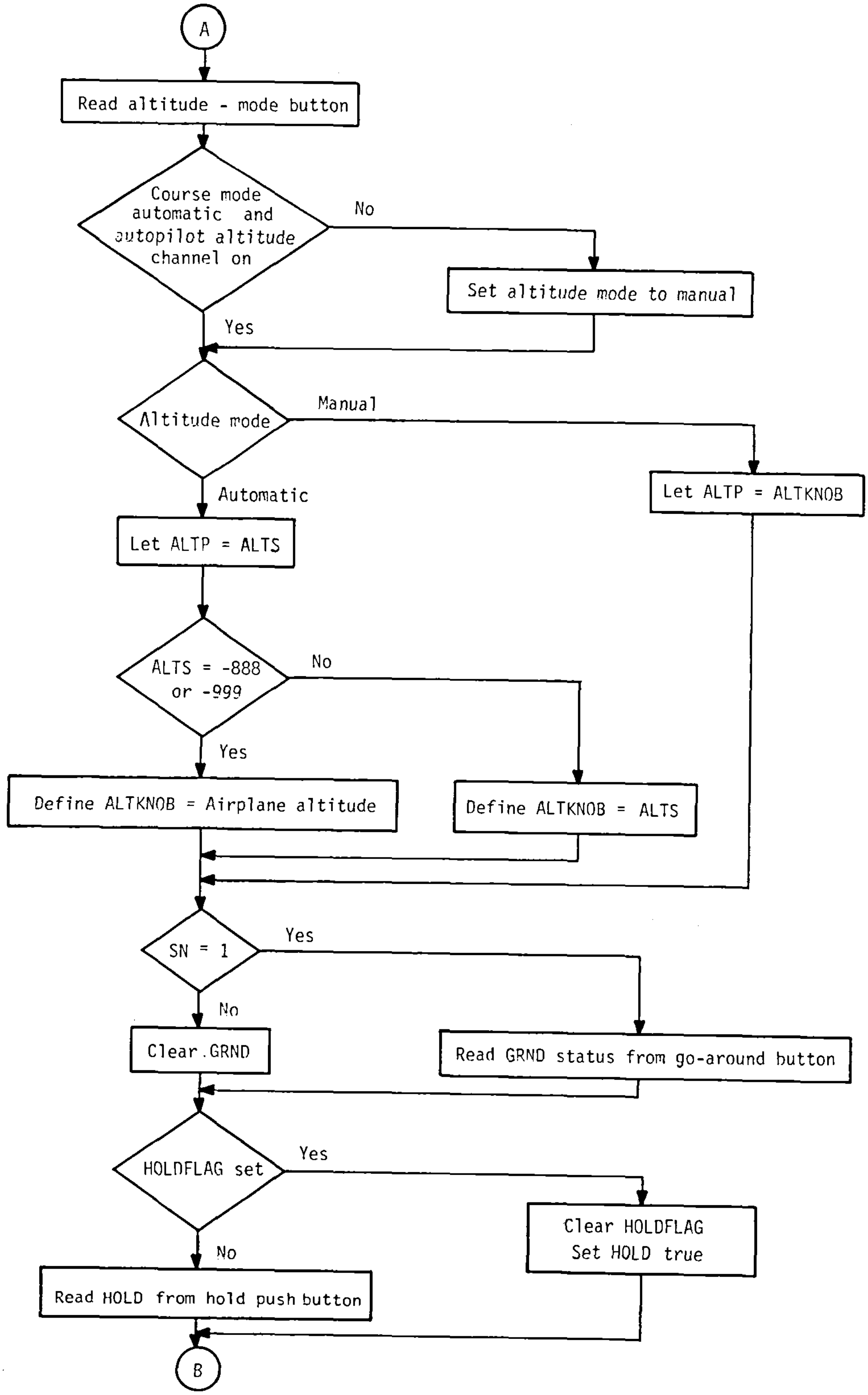


Figure 10.- Continued.

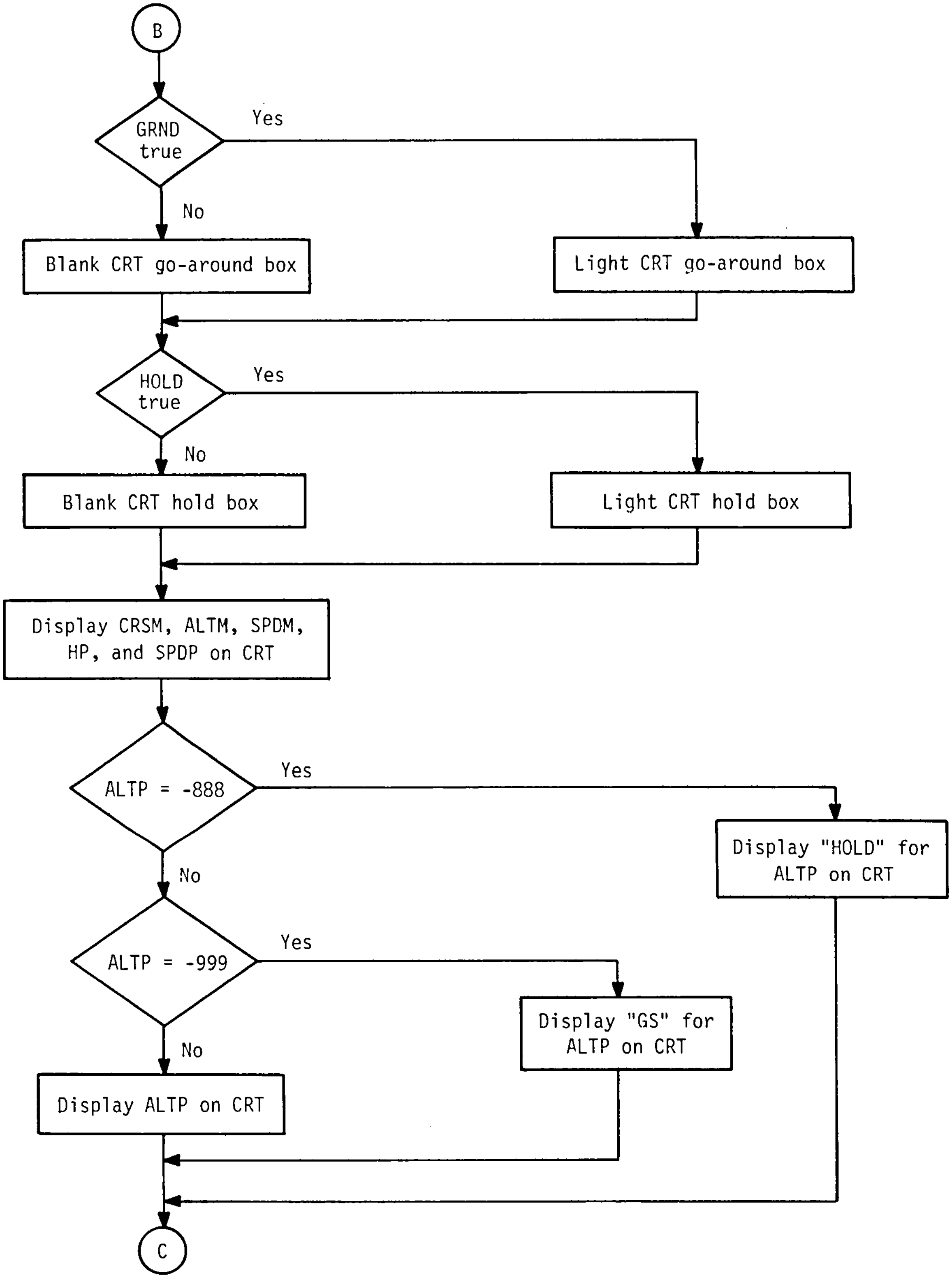


Figure 10.- Continued.

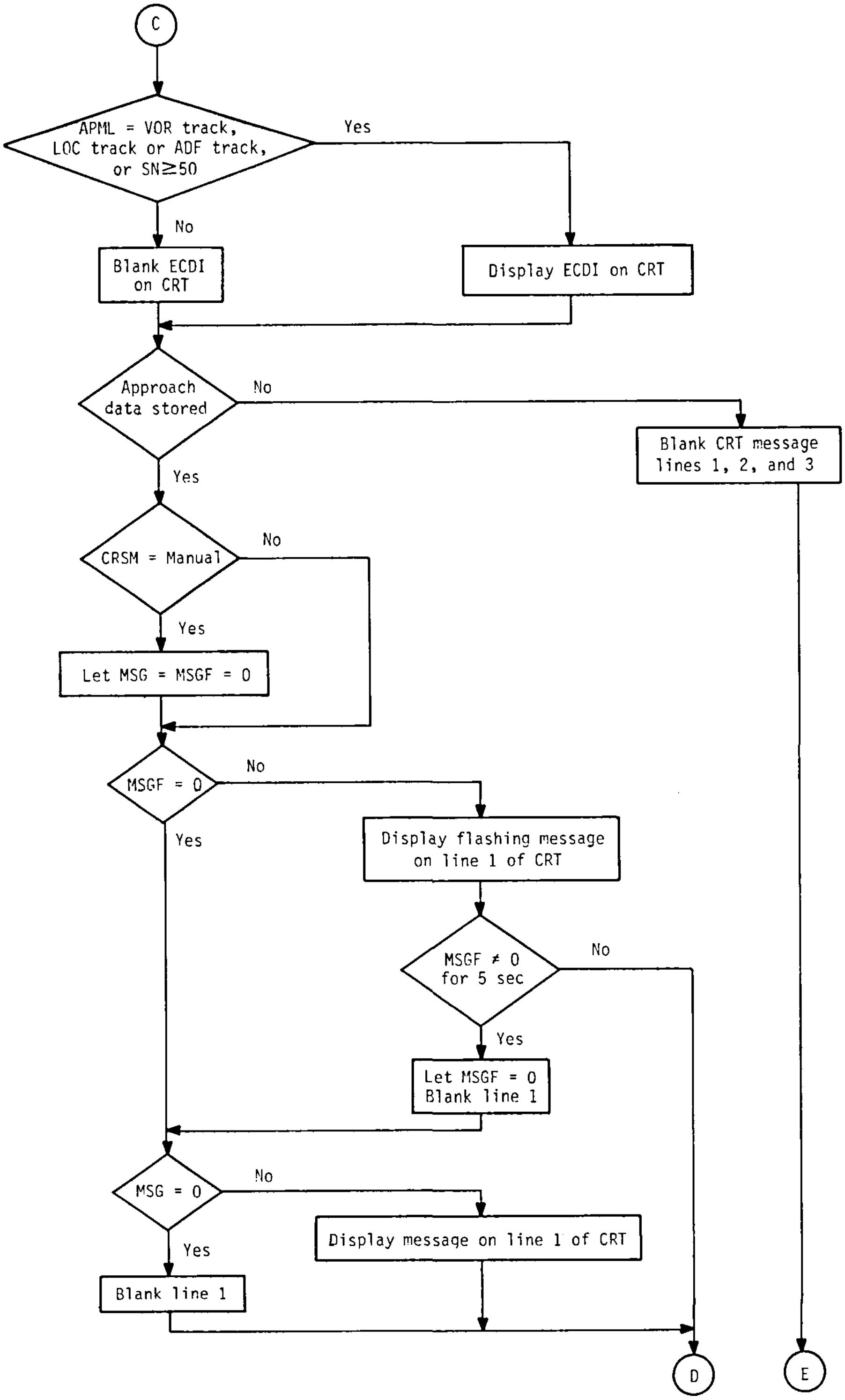


Figure 10.- Continued.

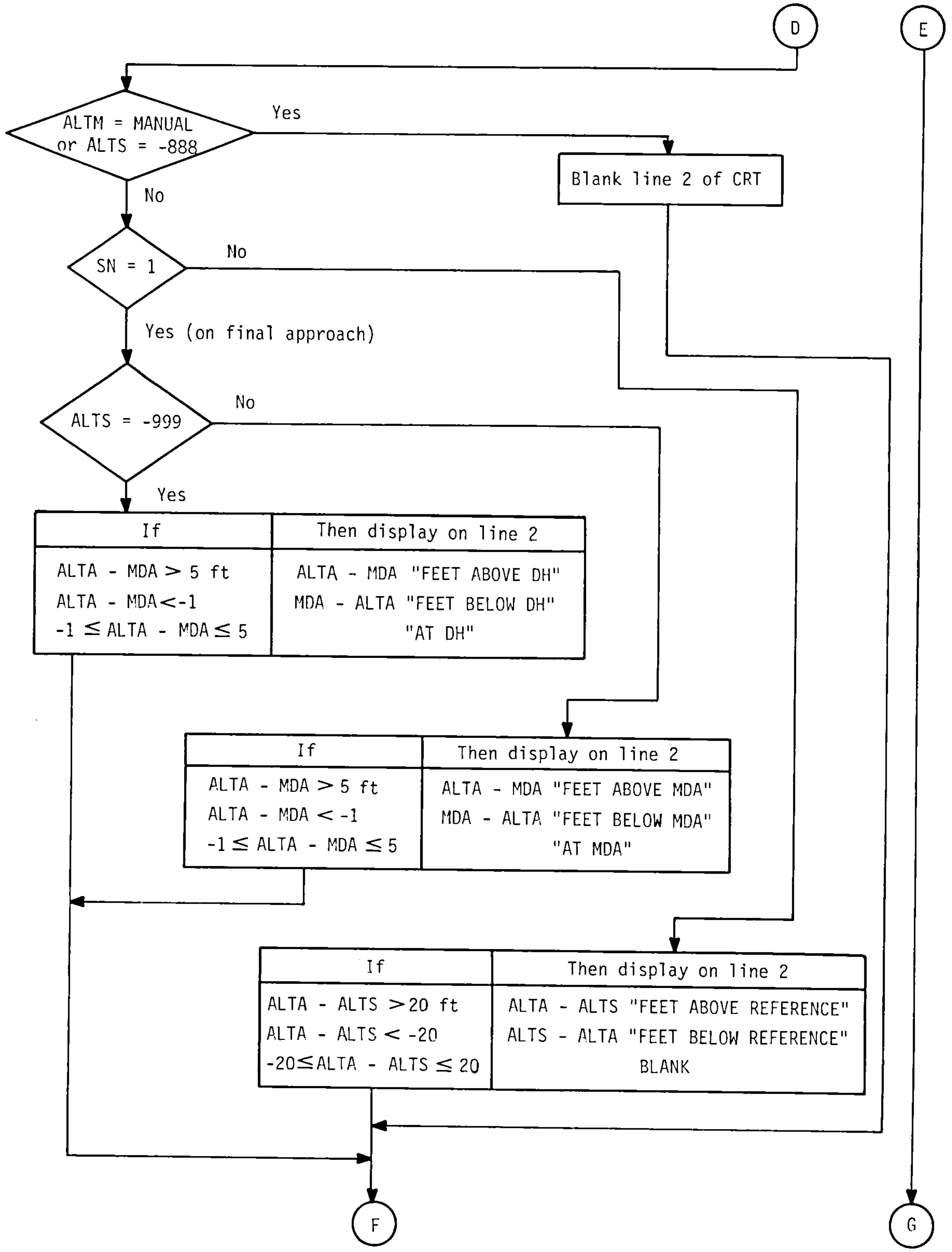


Figure 10.- Continued.

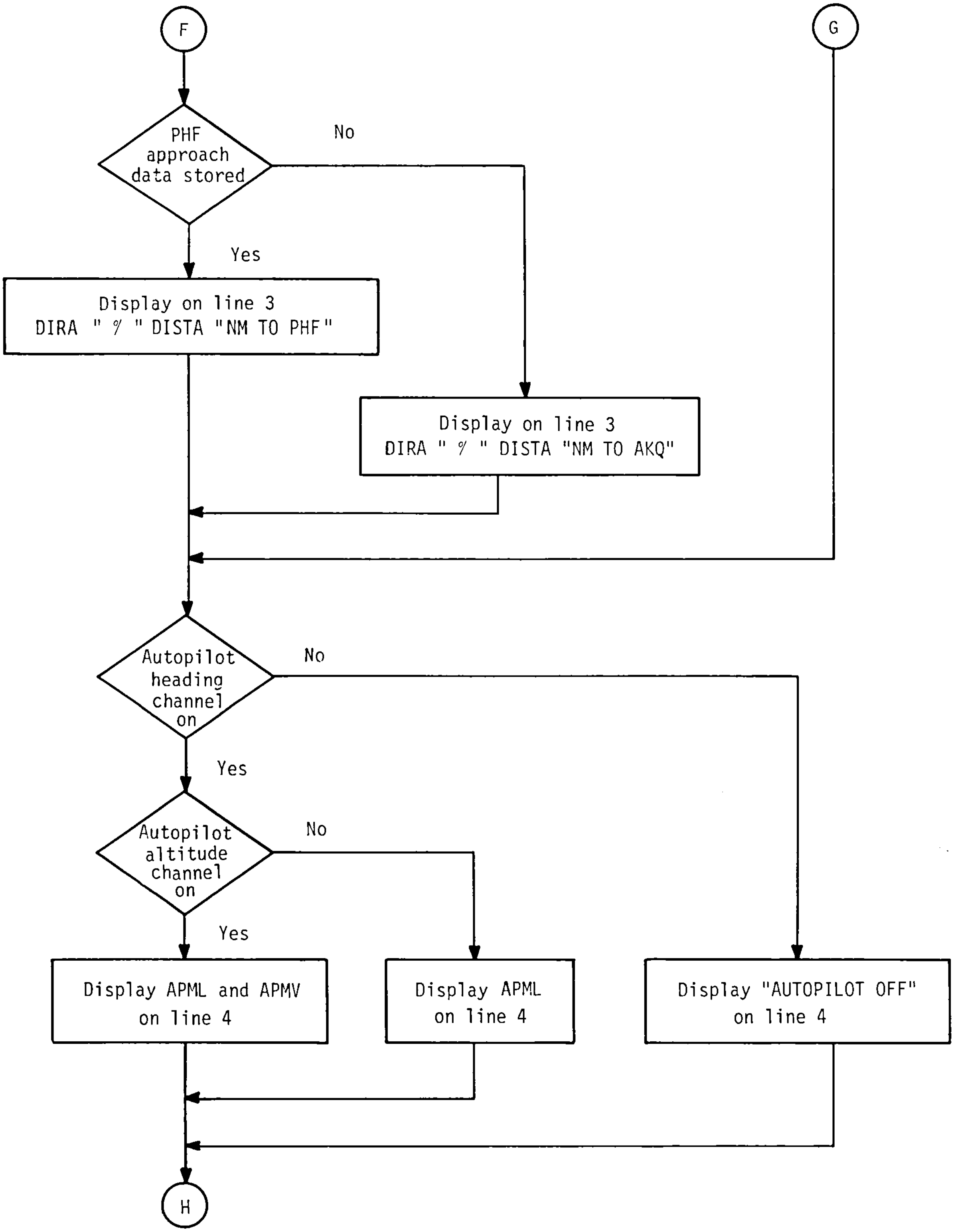


Figure 10.- Continued.

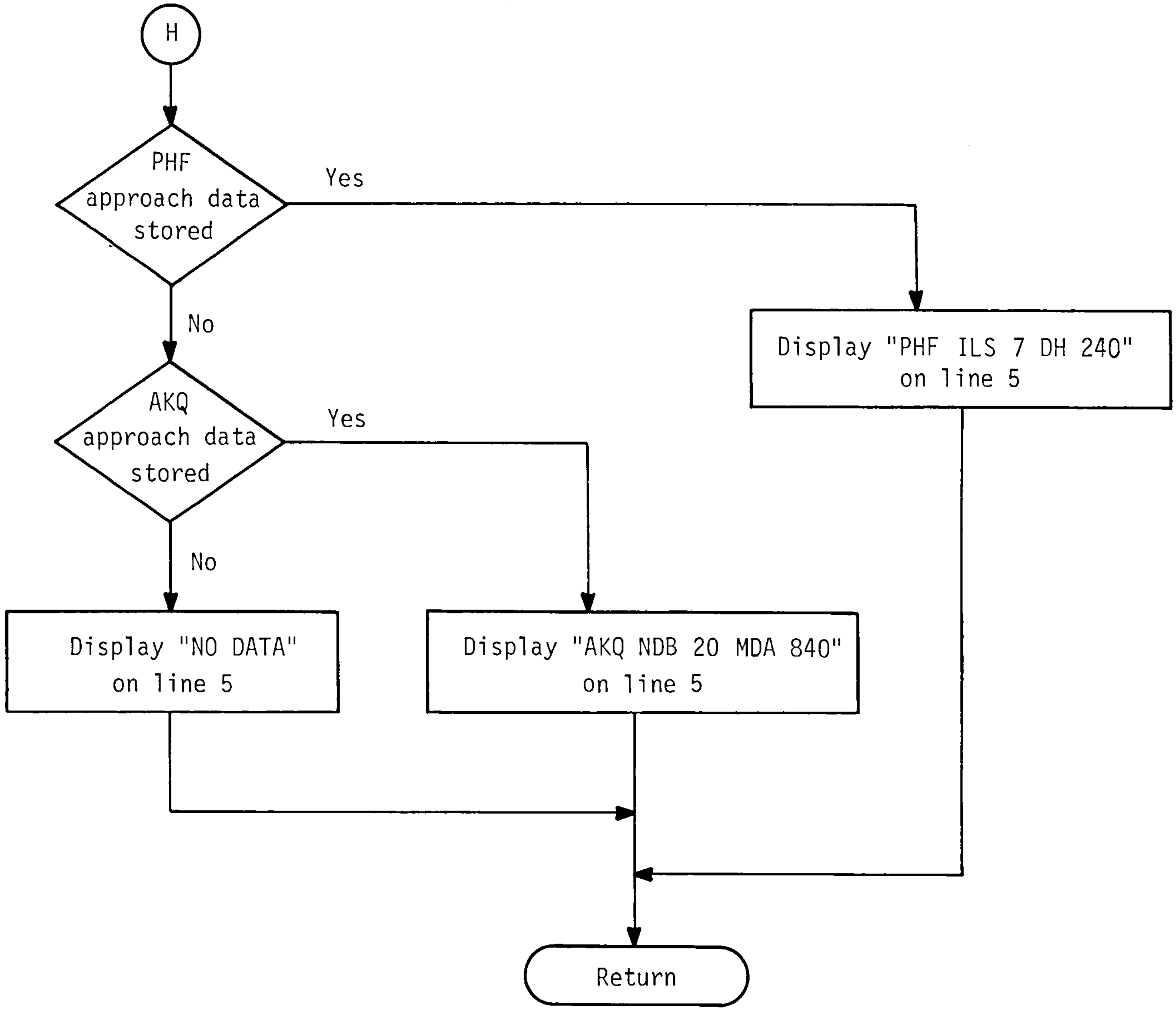


Figure 10.- Concluded.

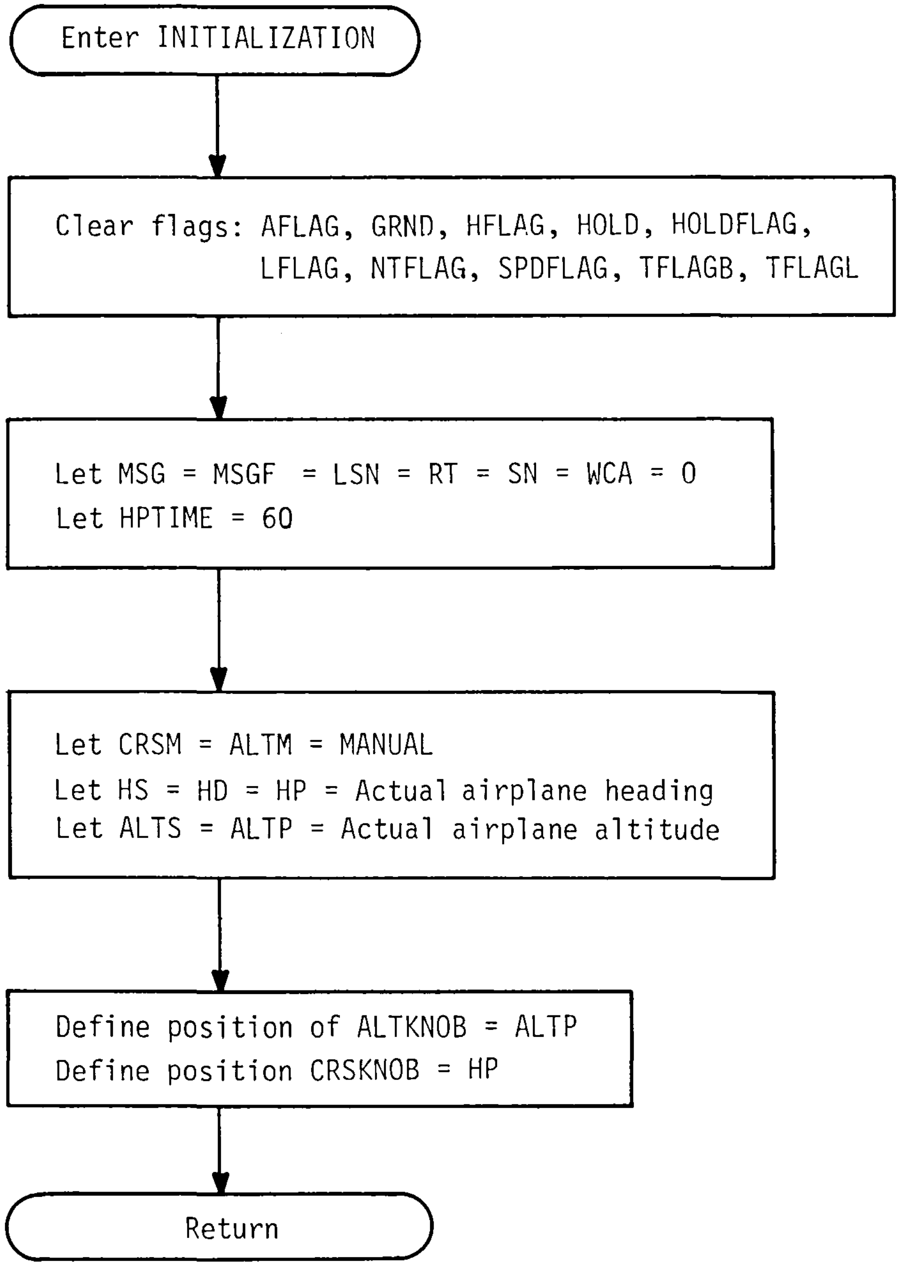


Figure 11.- Subroutine INITIALIZATION for DISPLAY.

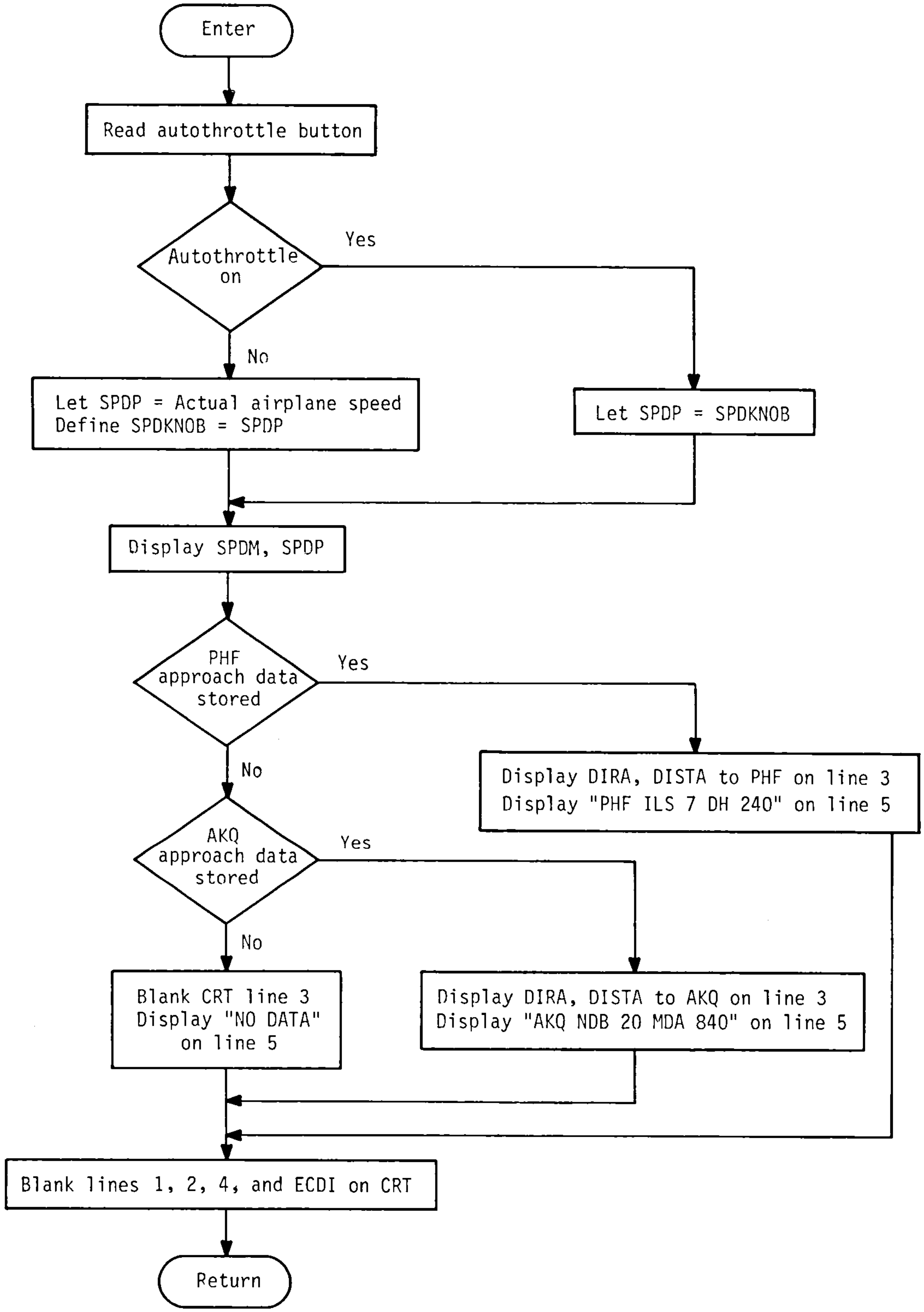


Figure 12.- ATAS standby logic for subroutine DISPLAY.

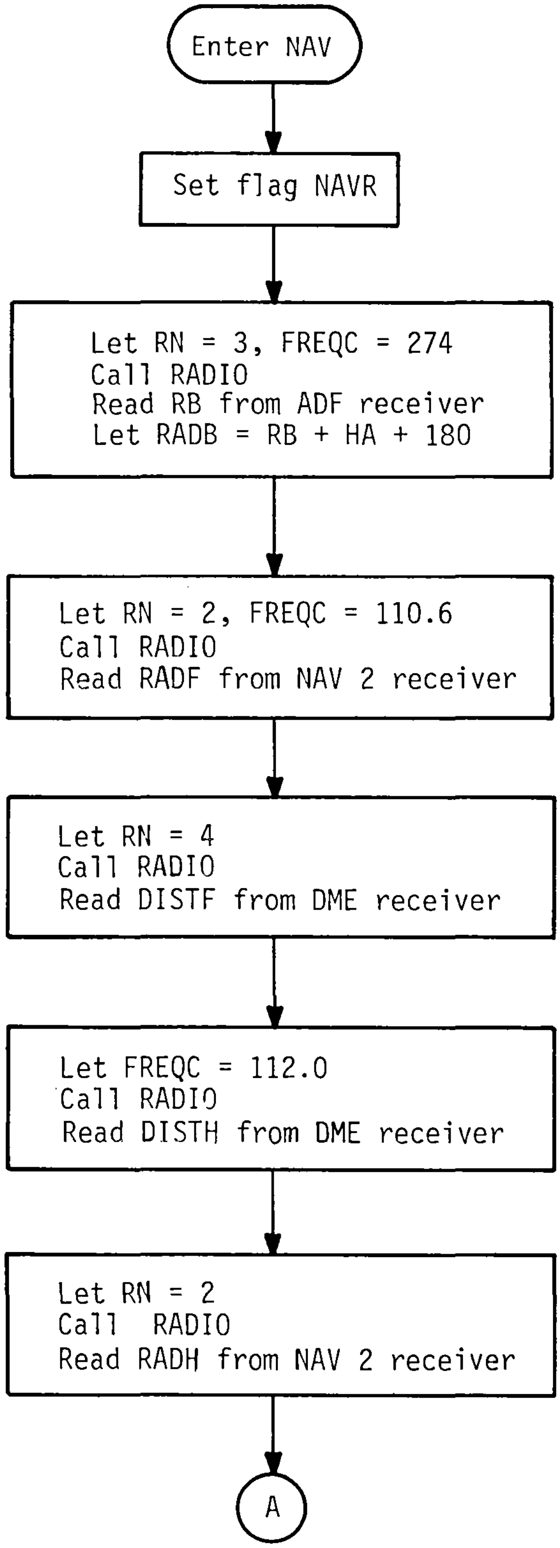


Figure 13.- Subroutine NAV for Wakefield approach.

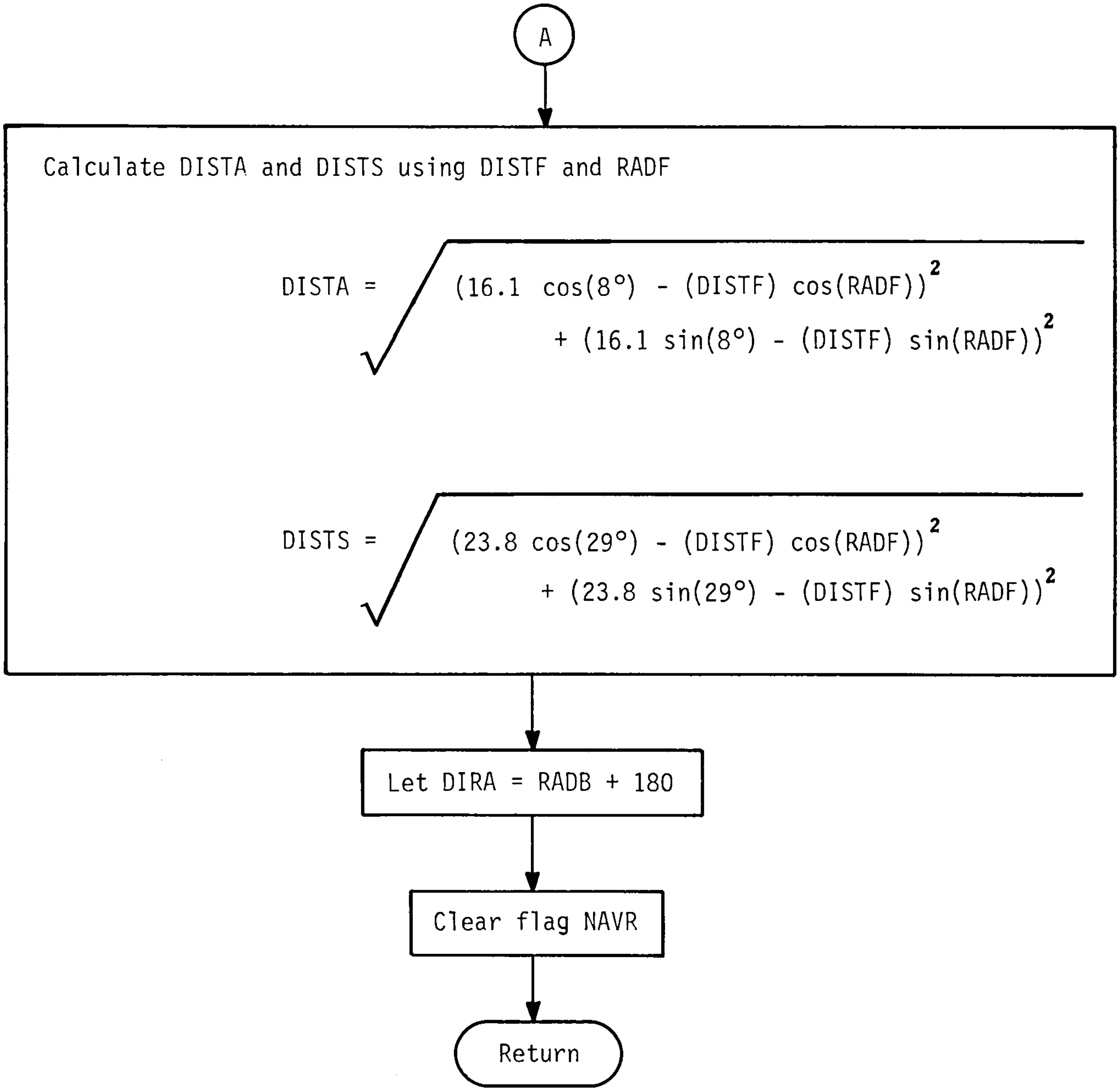


Figure 13.- Concluded.

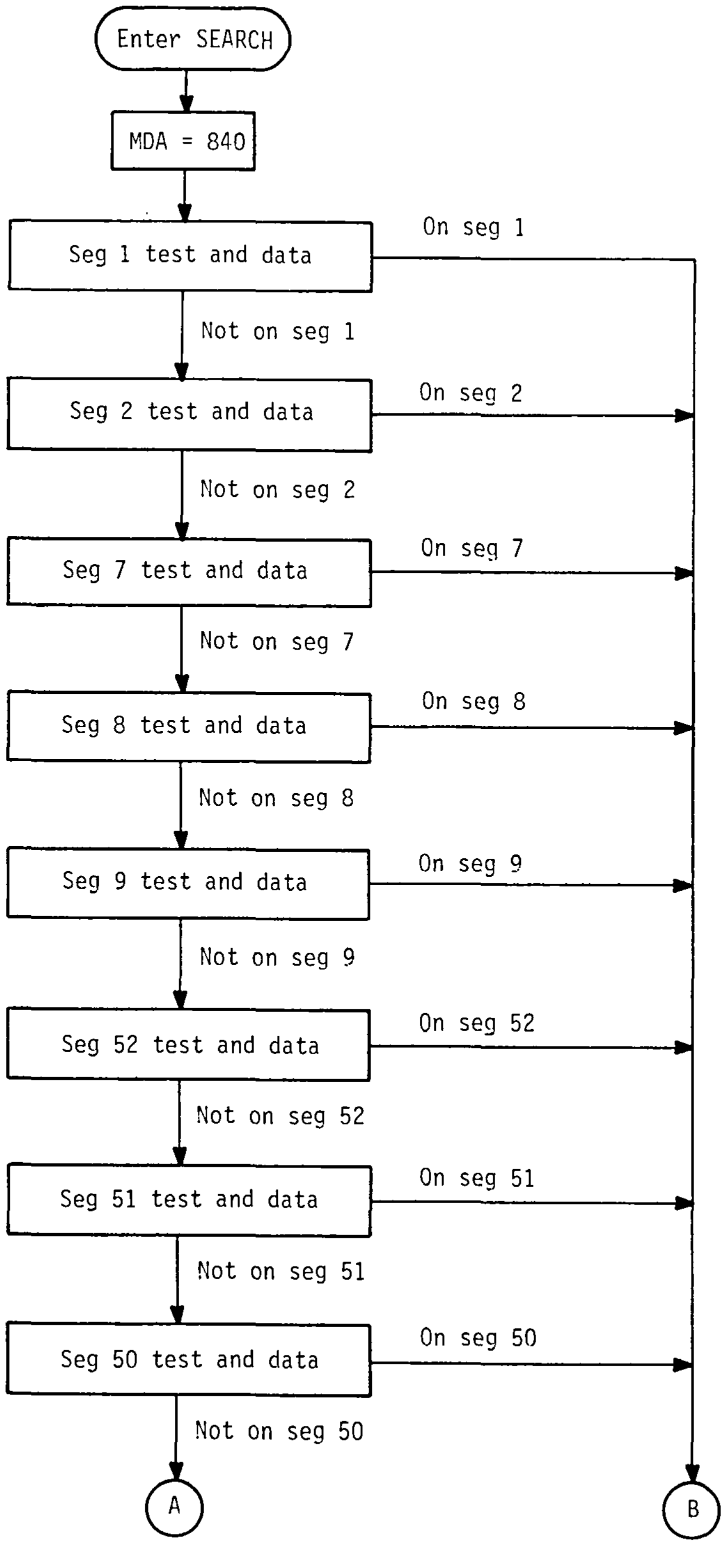


Figure 14.- Subroutine SEARCH for Wakefield Municipal Airport.

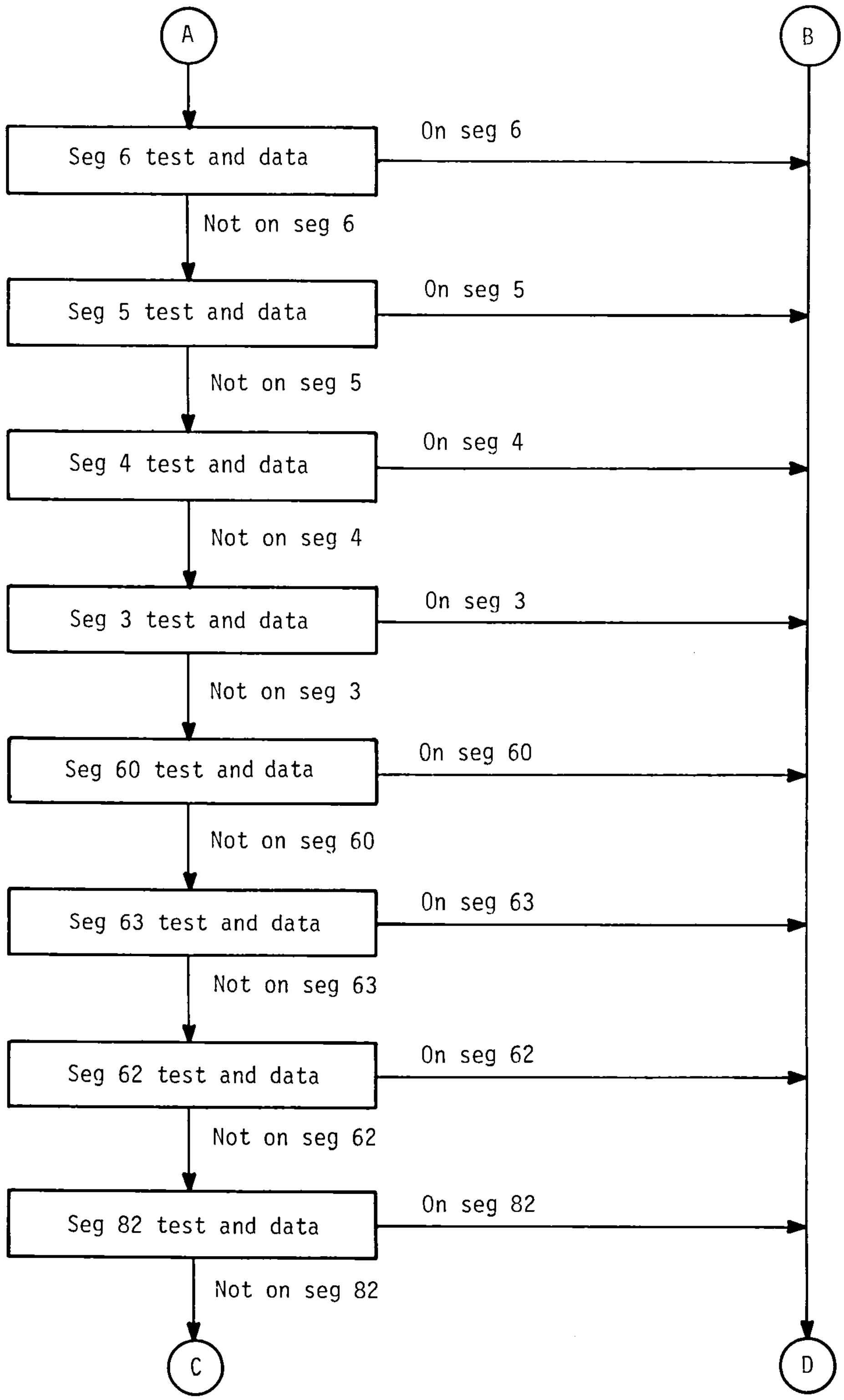


Figure 14.- Continued.

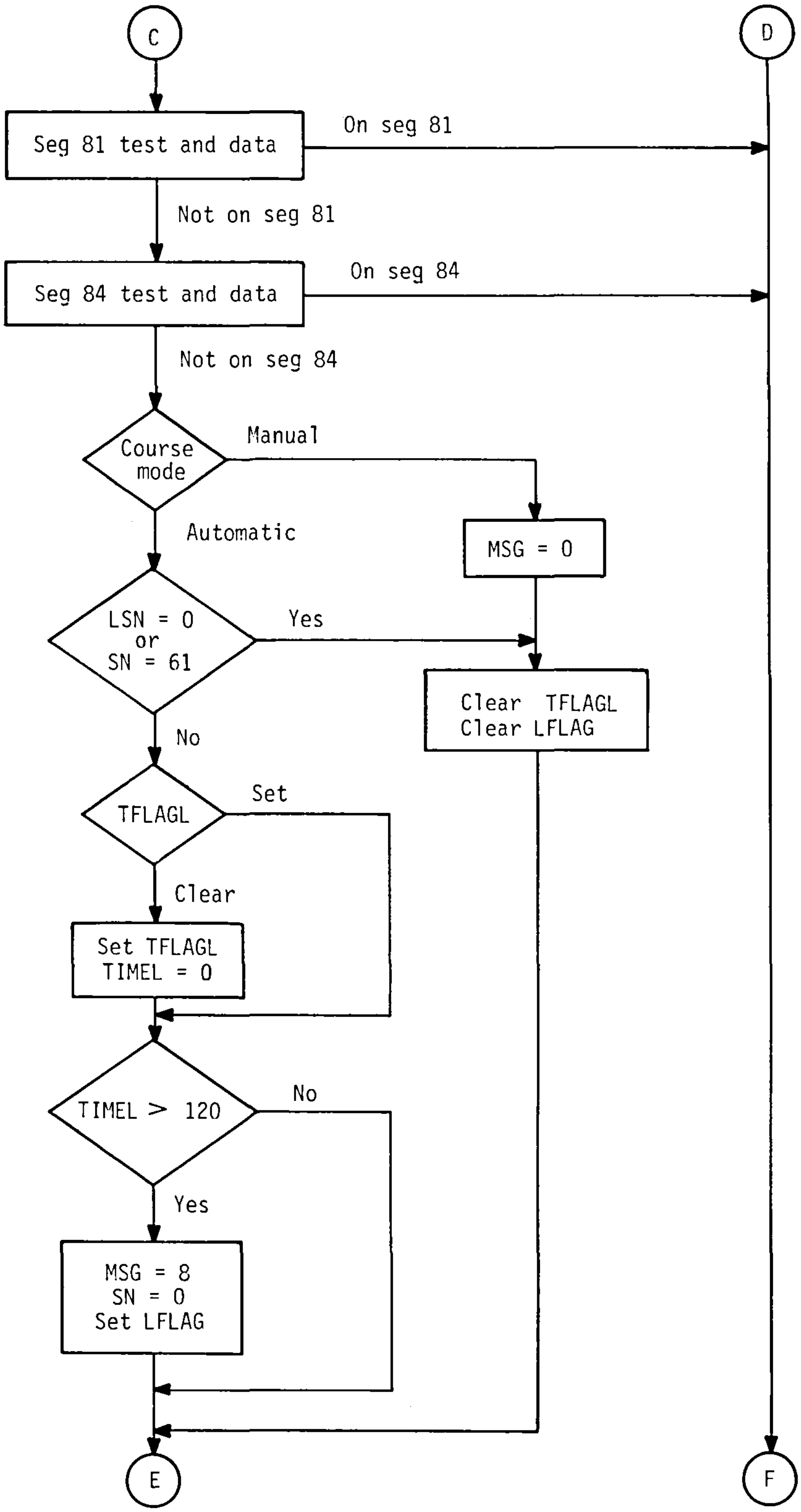


Figure 14.- Continued.

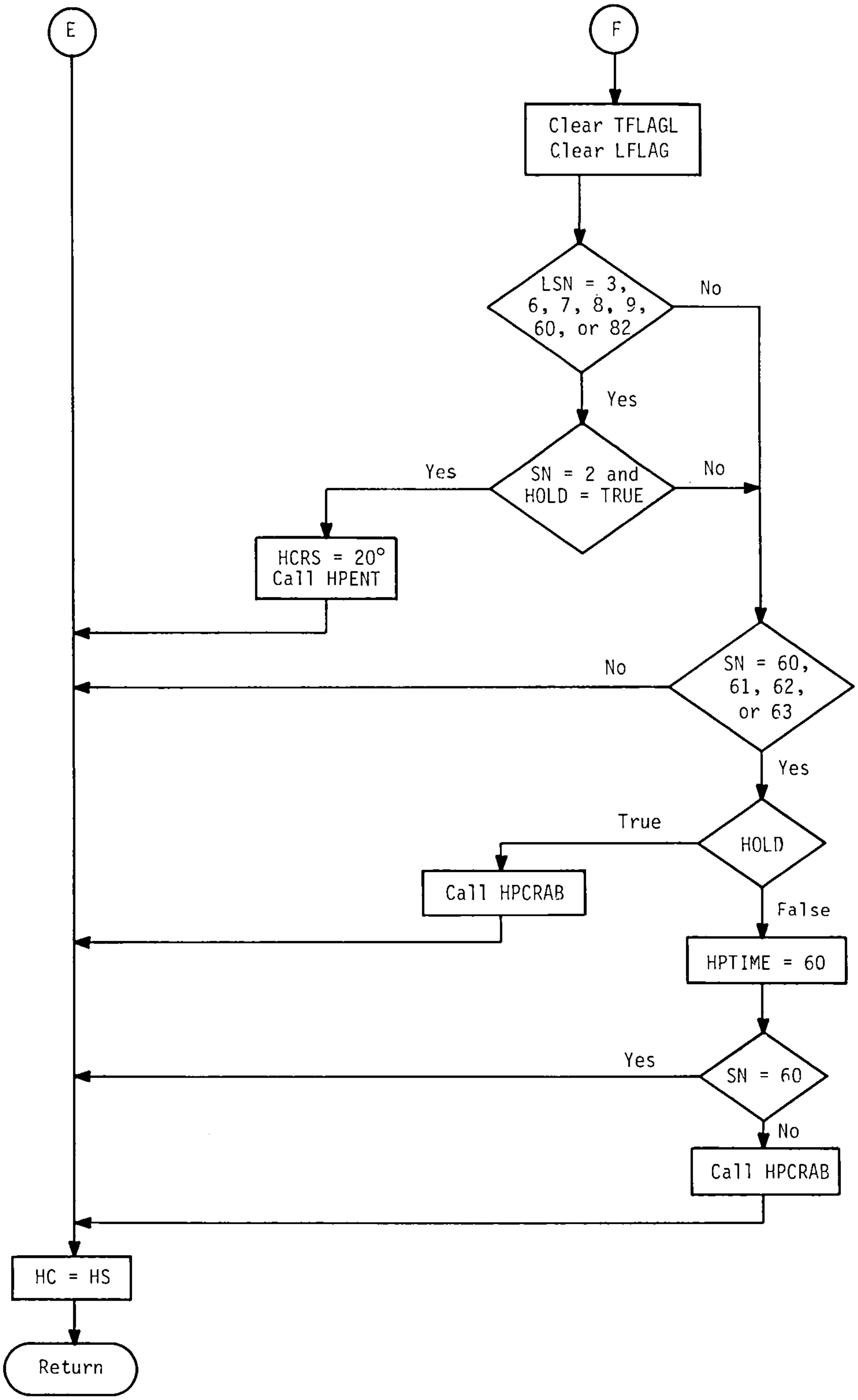


Figure 14.- Concluded.

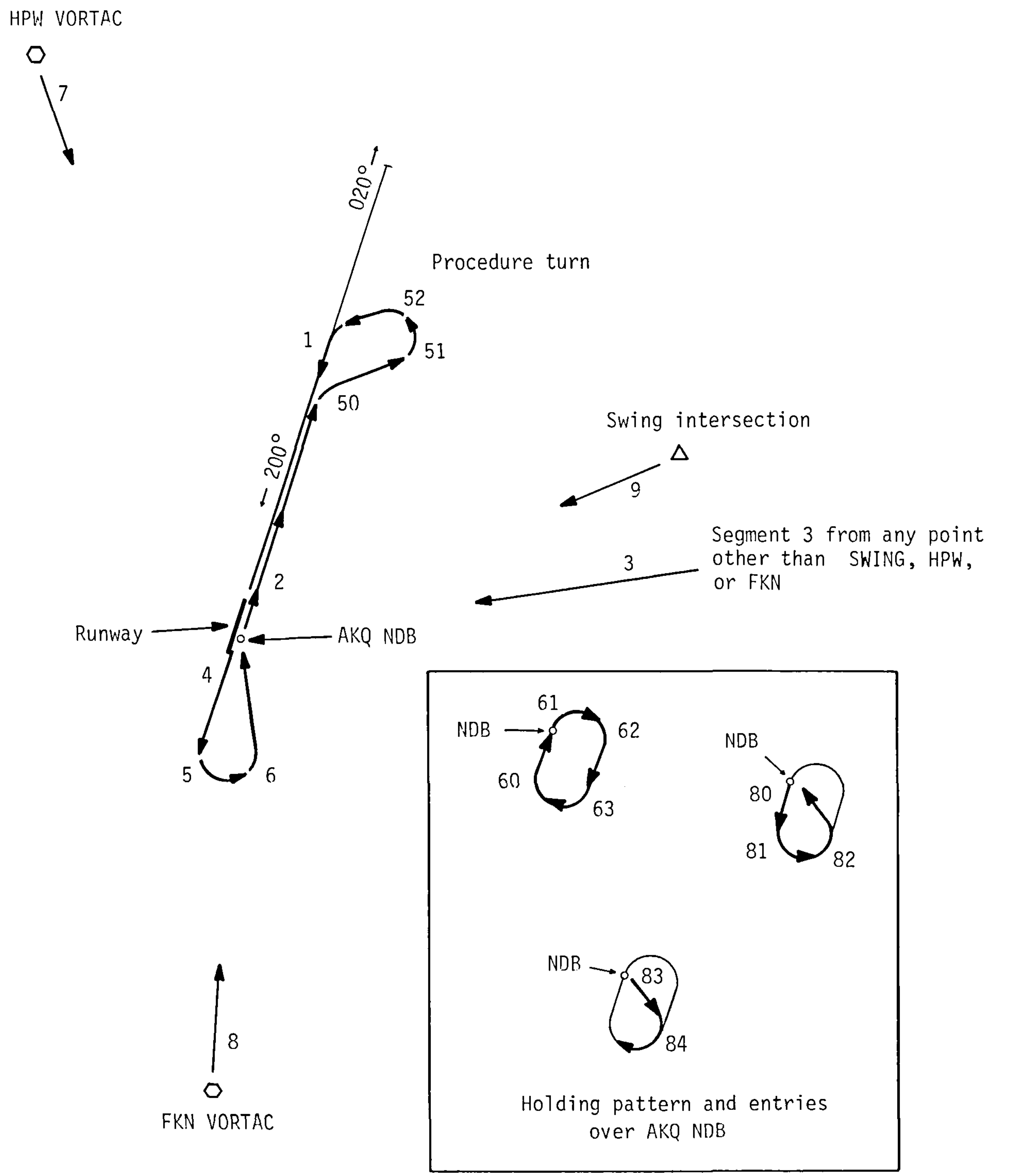


Figure 15.- Segmentation of Wakefield NDB approach.

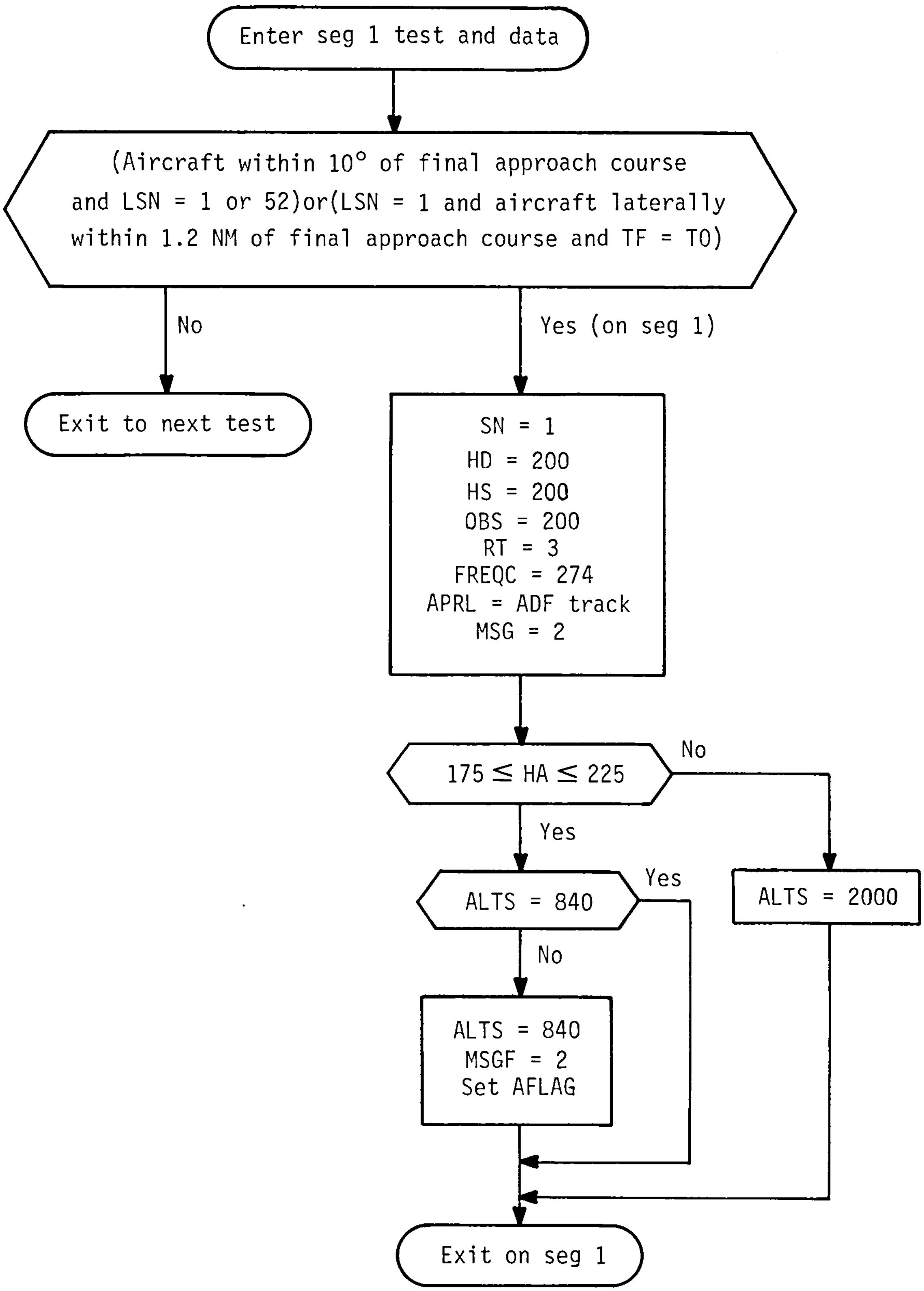


Figure 16.- Segment test and data routines.

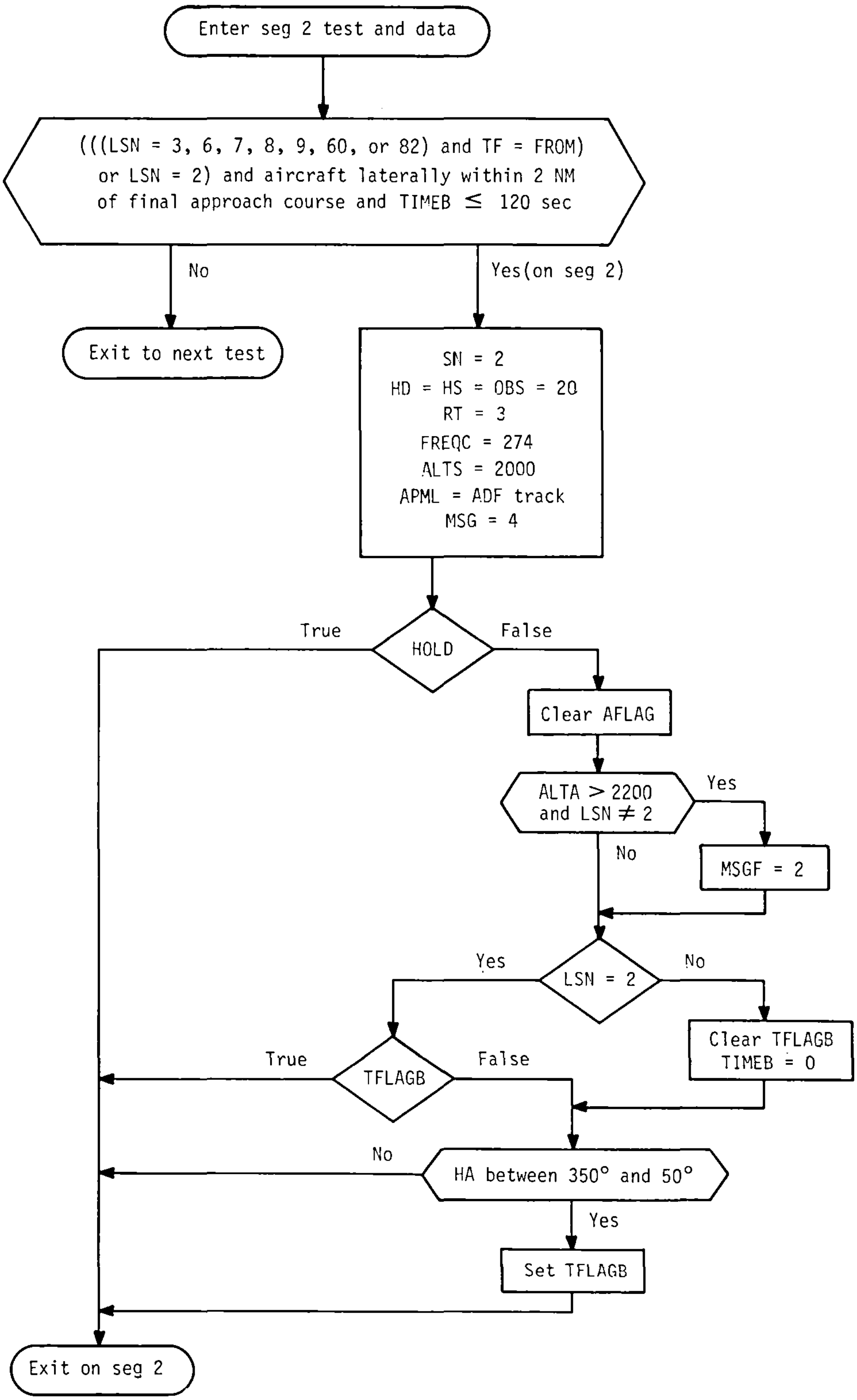


Figure 16.- Continued.

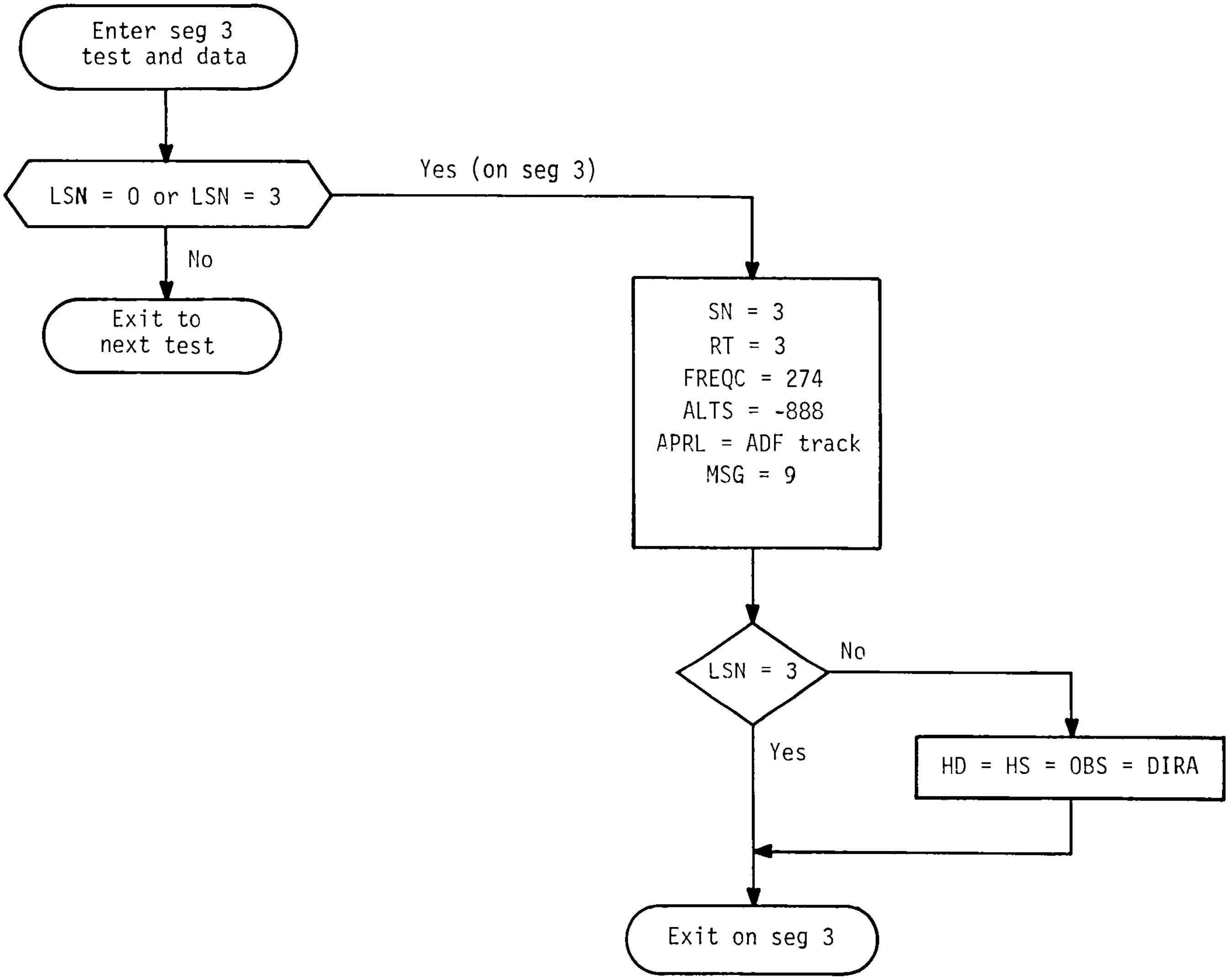


Figure 16.- Continued.

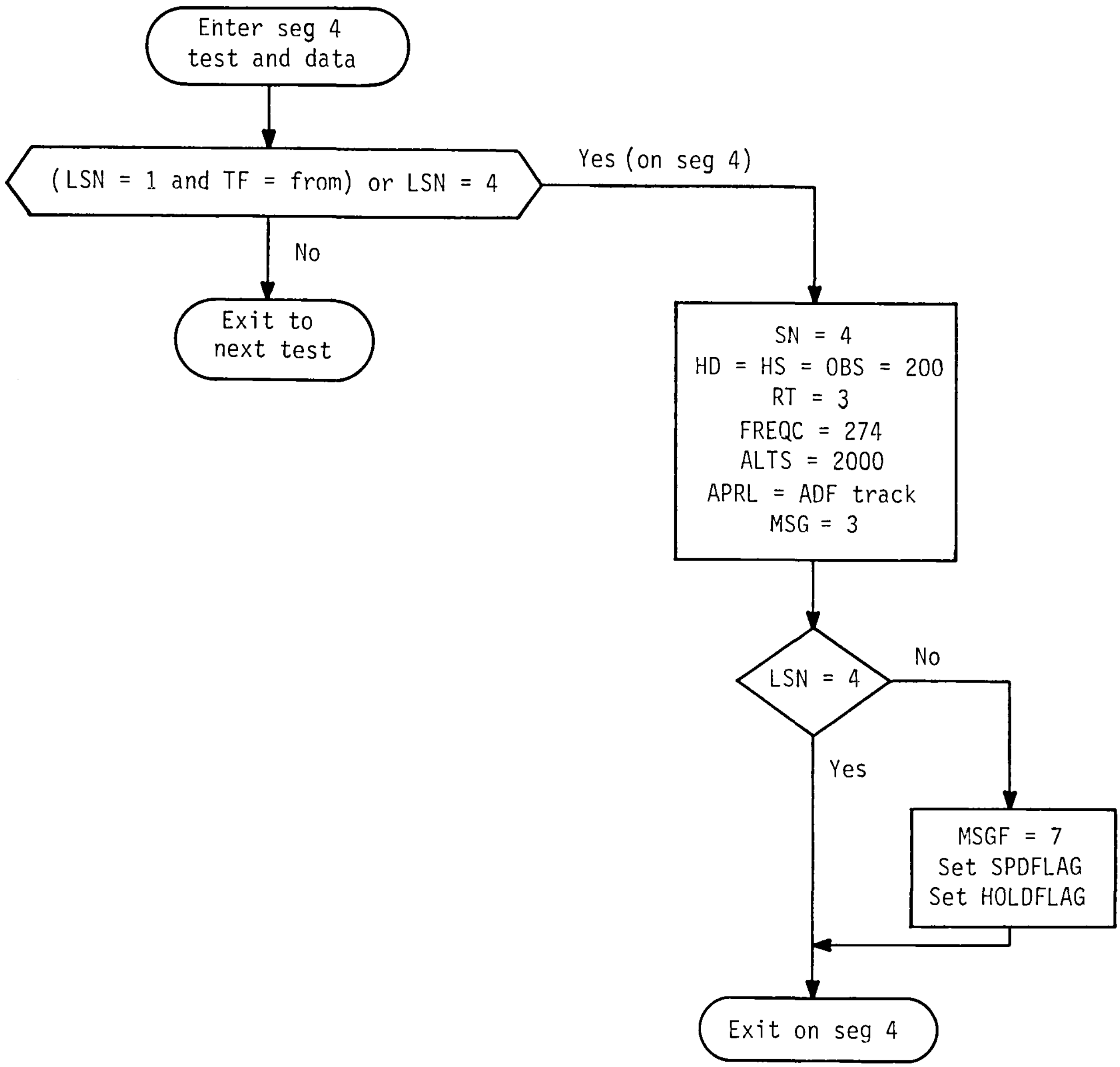


Figure 16.- Continued.

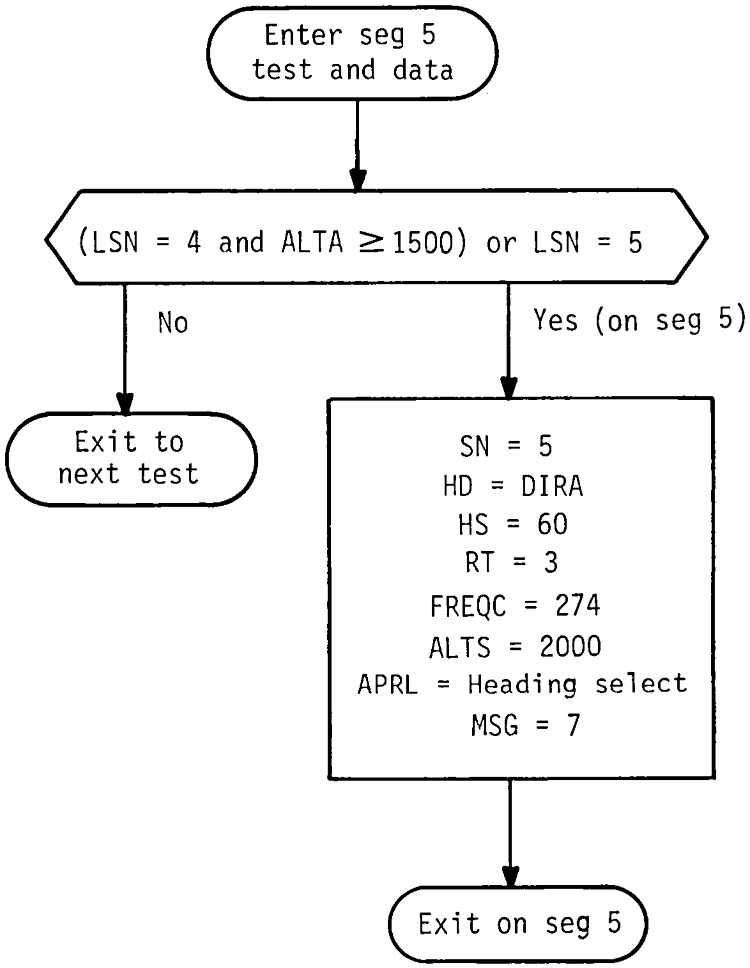
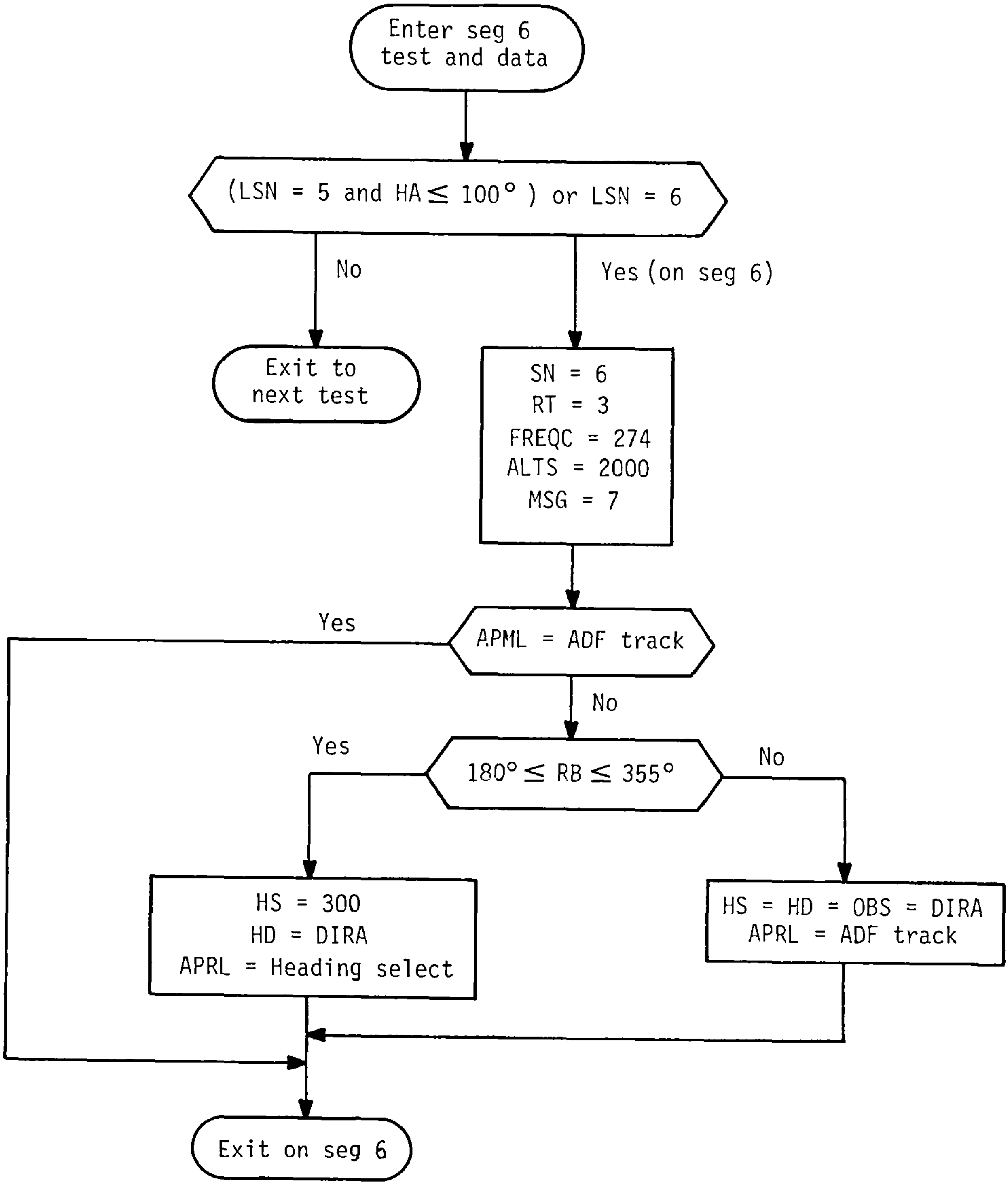


Figure 16.- Continued.



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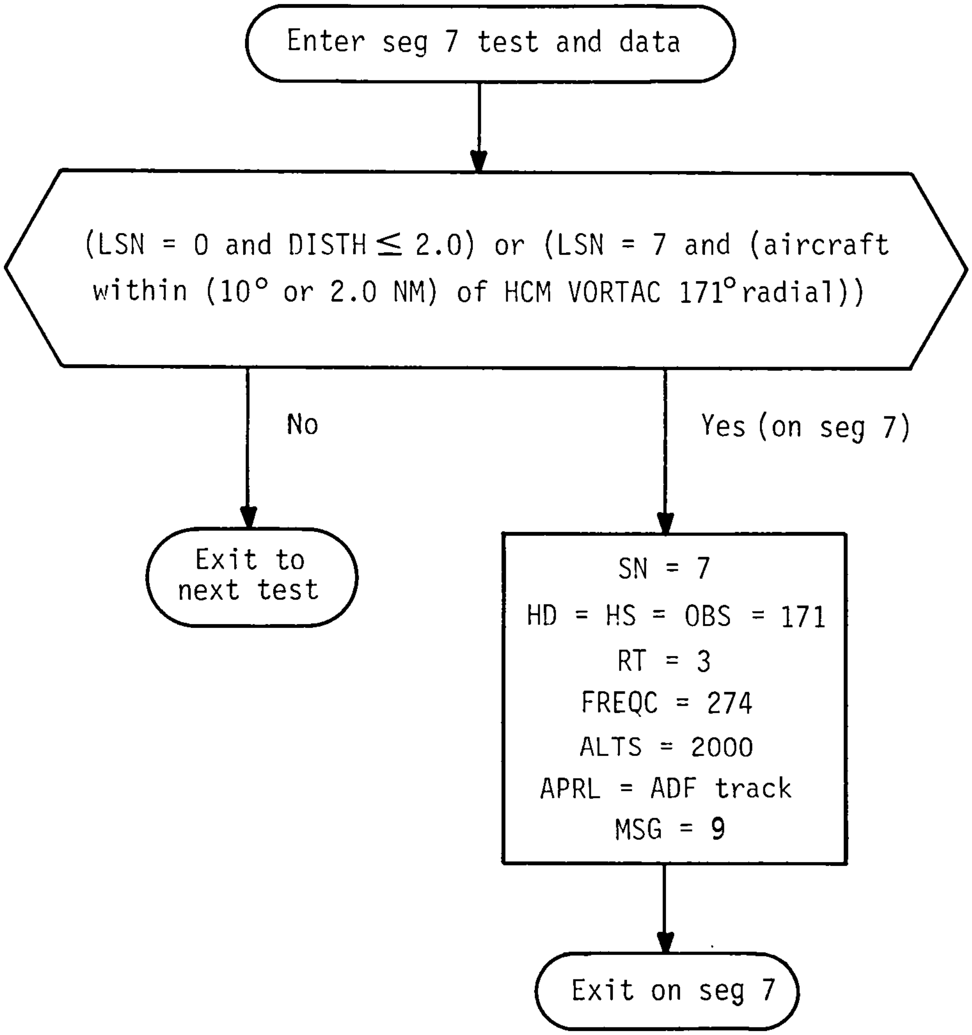

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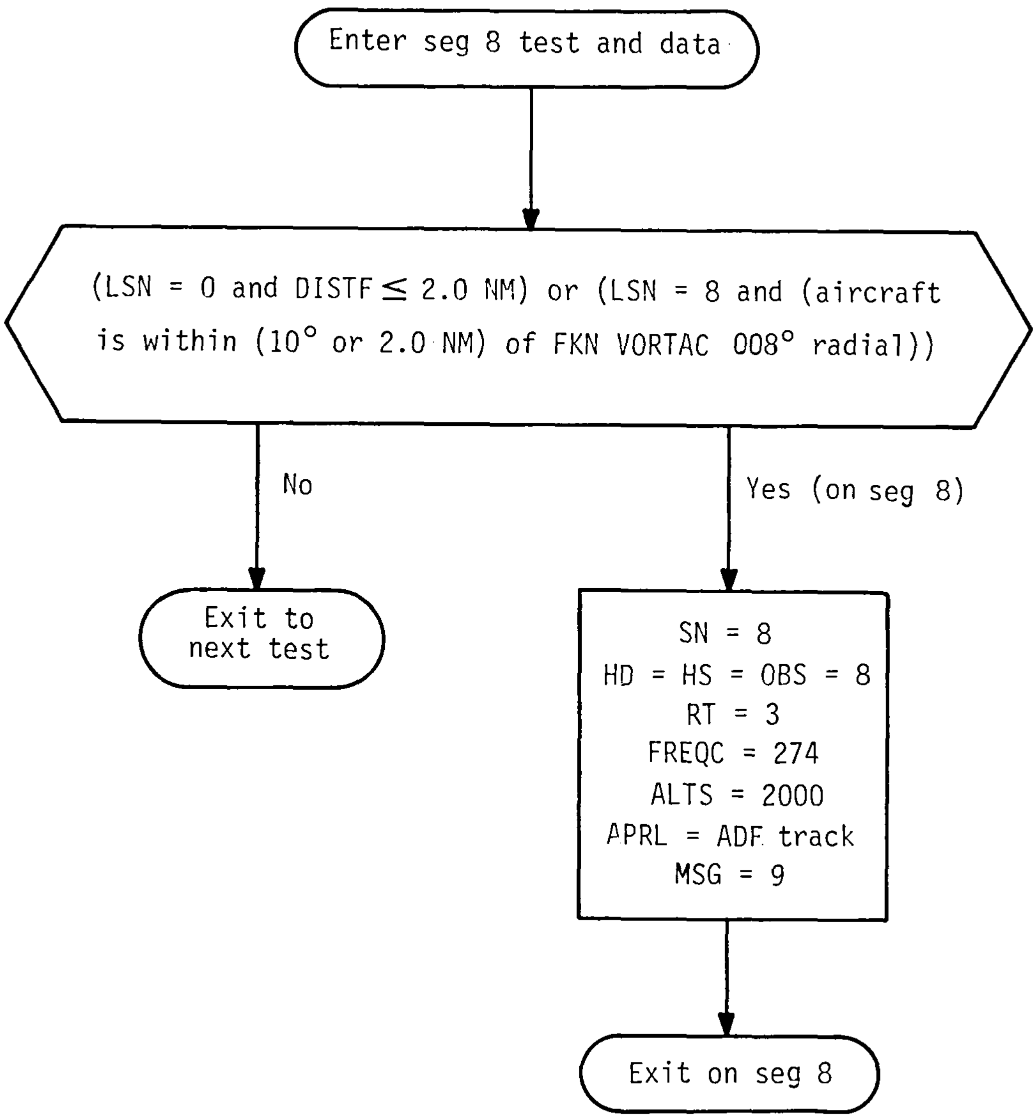

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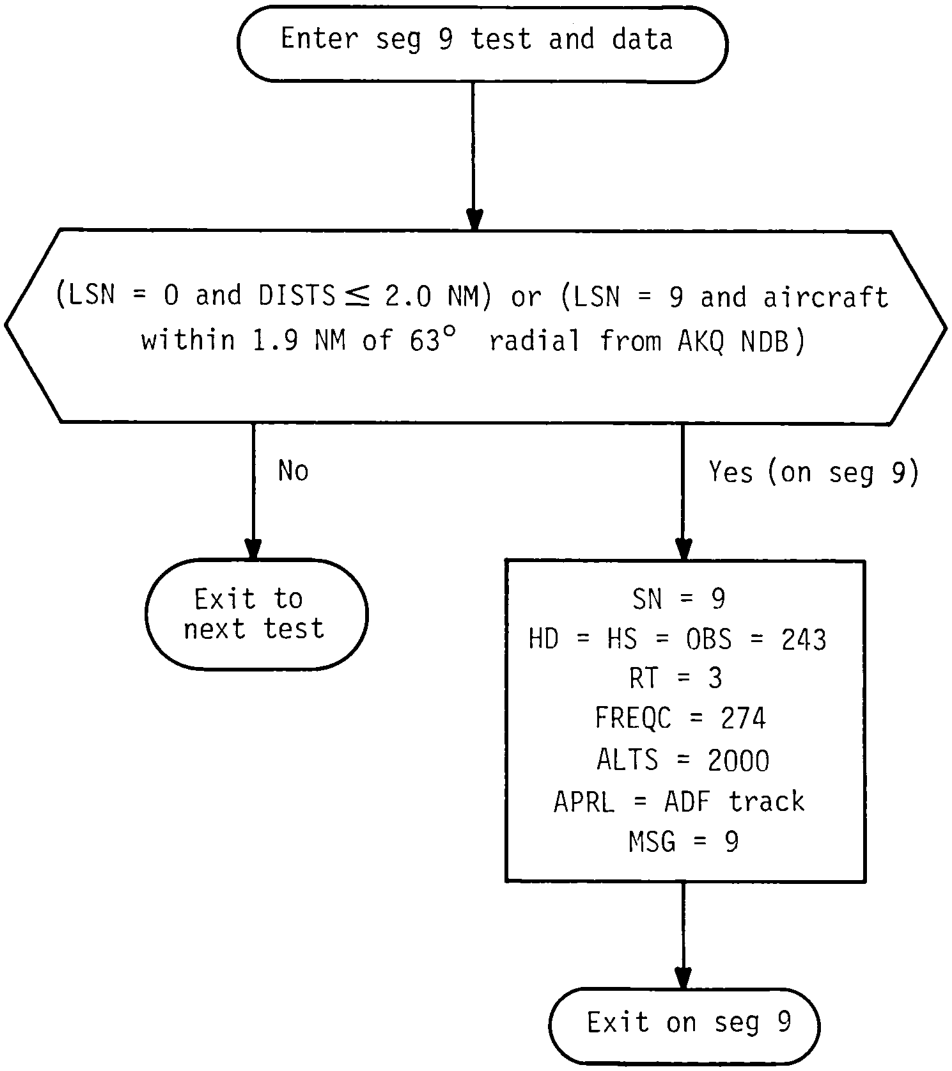

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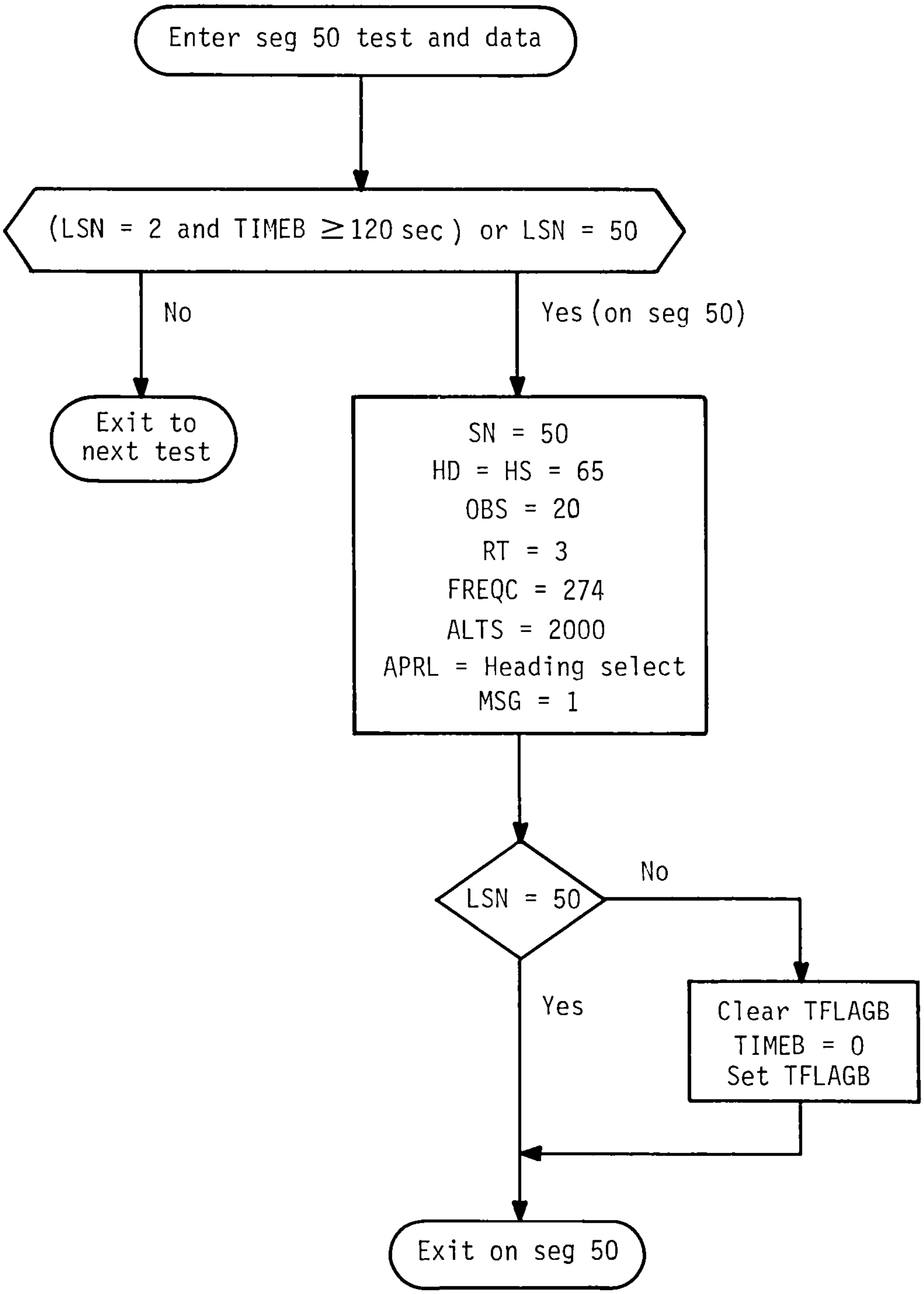

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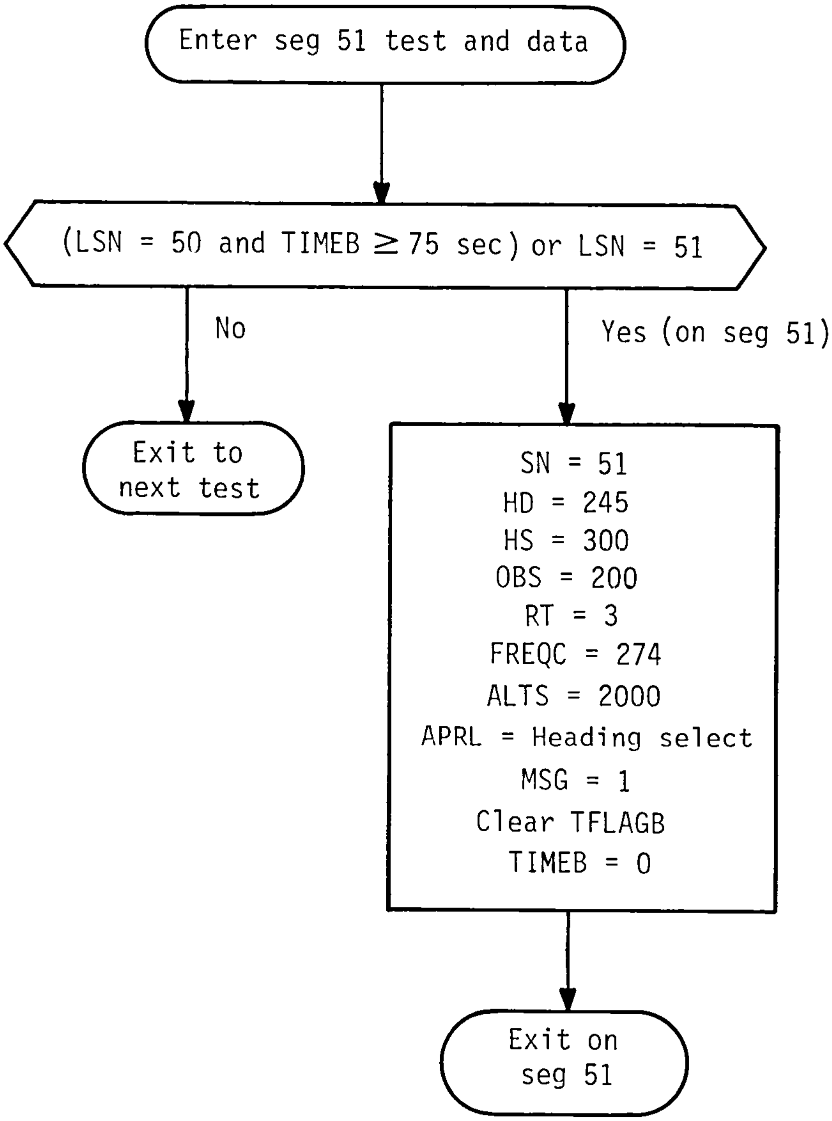

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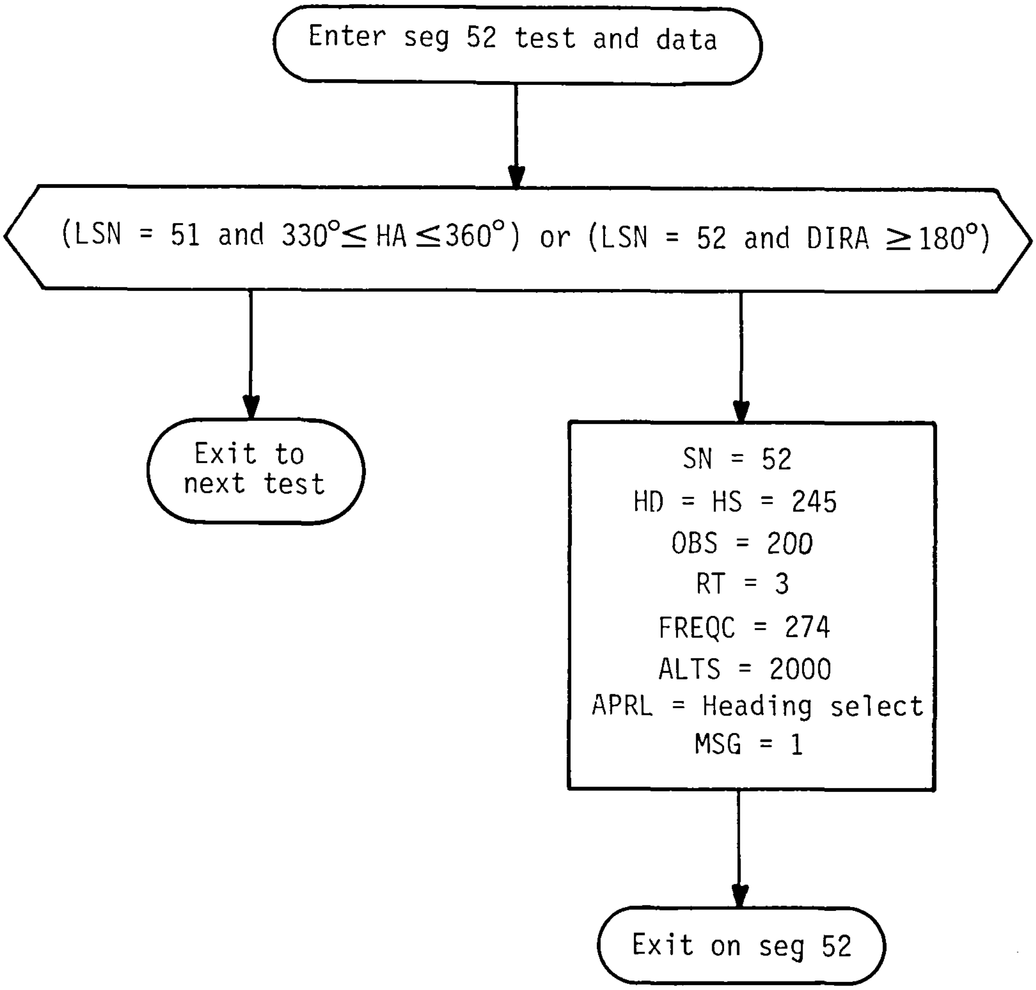

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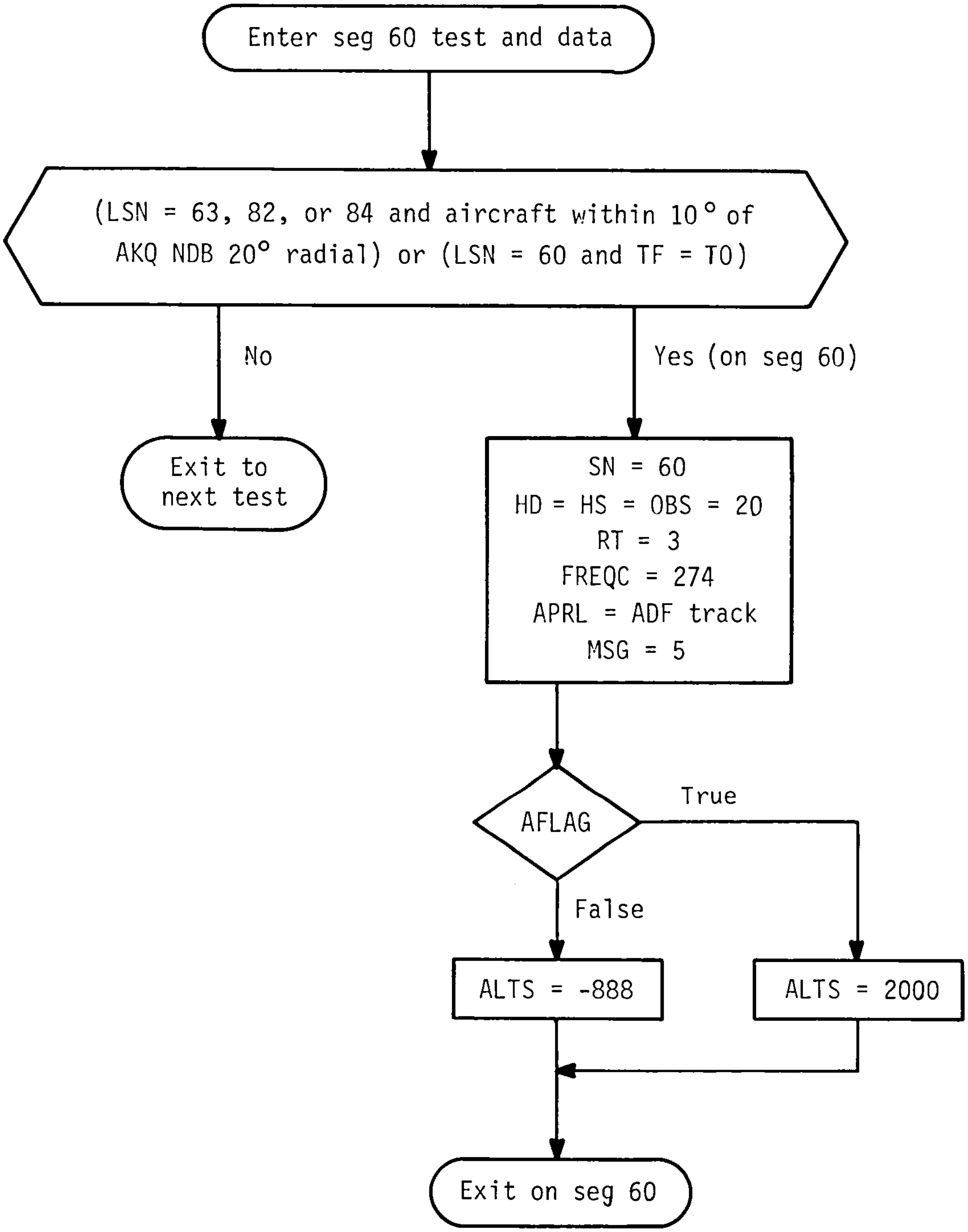

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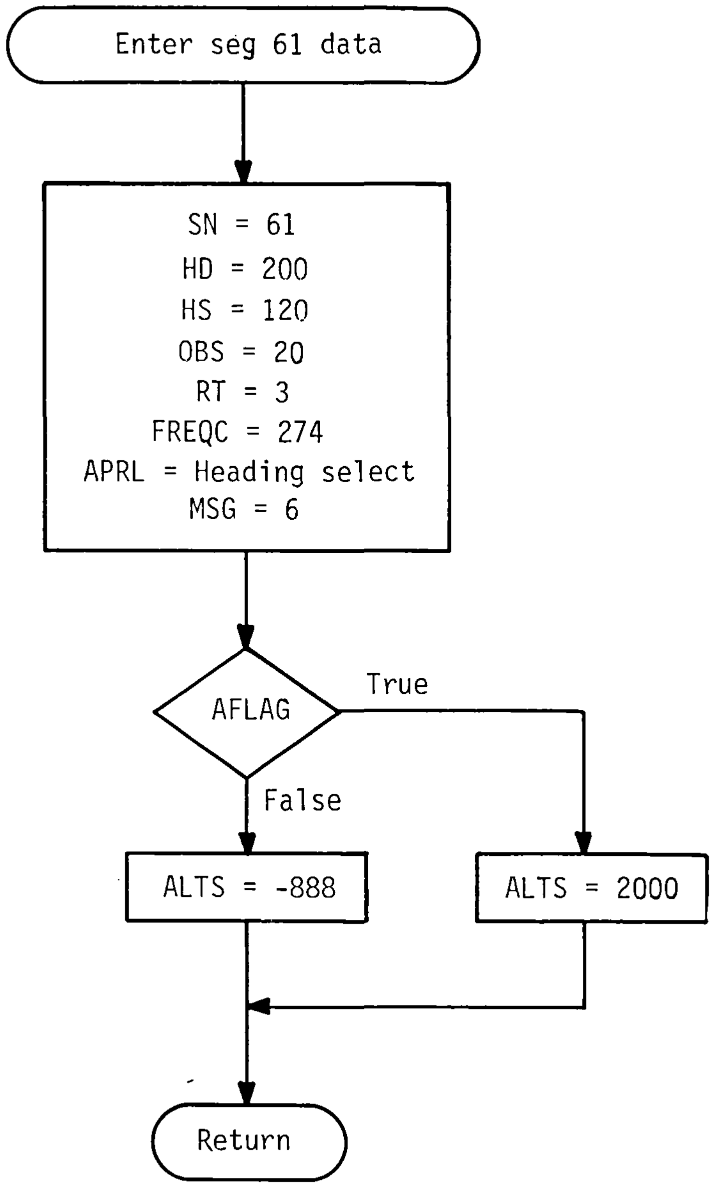

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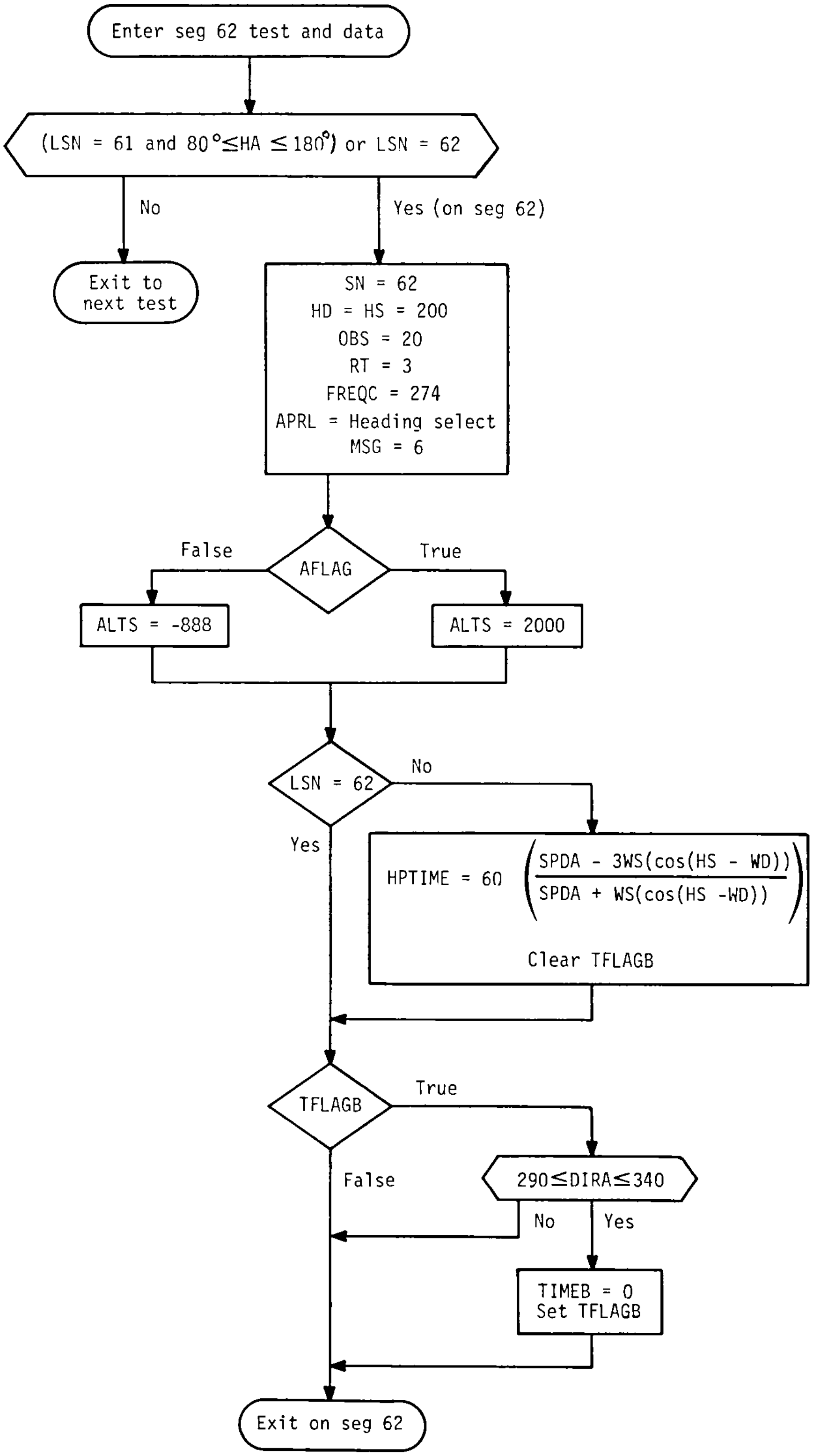

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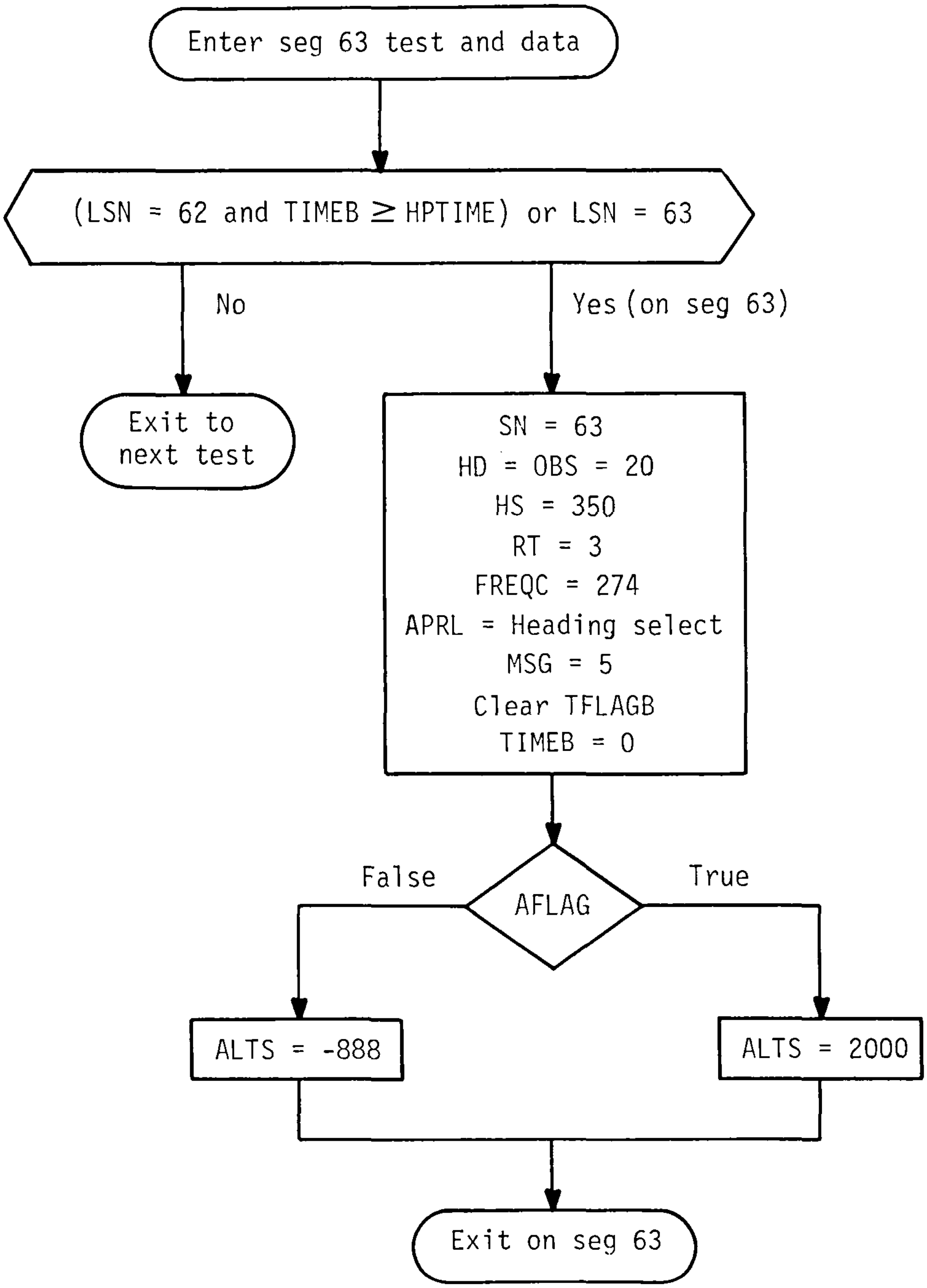

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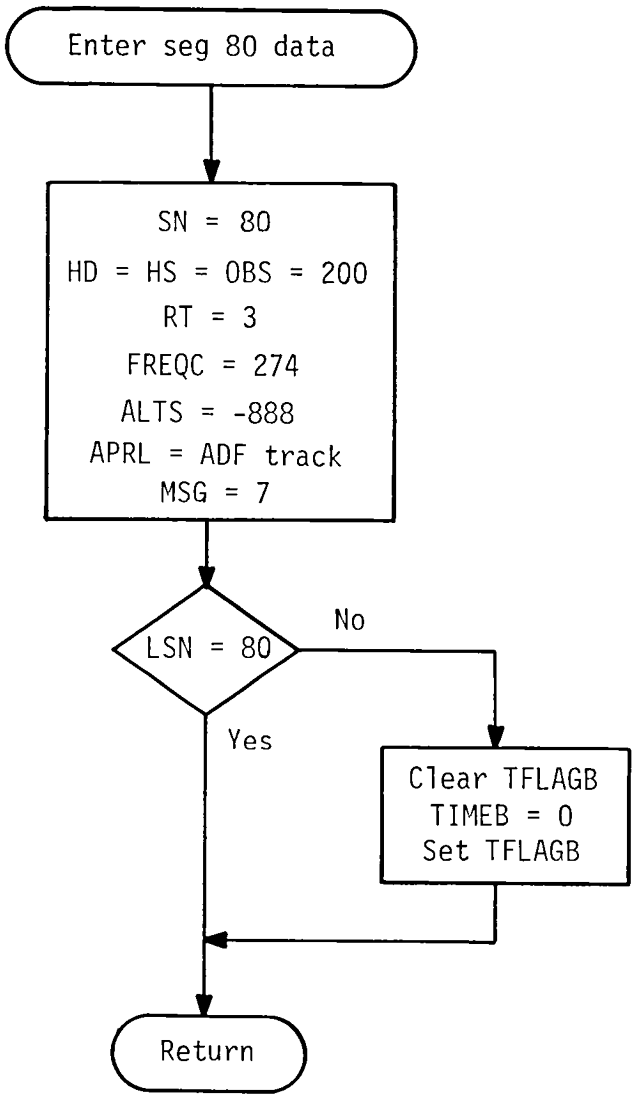

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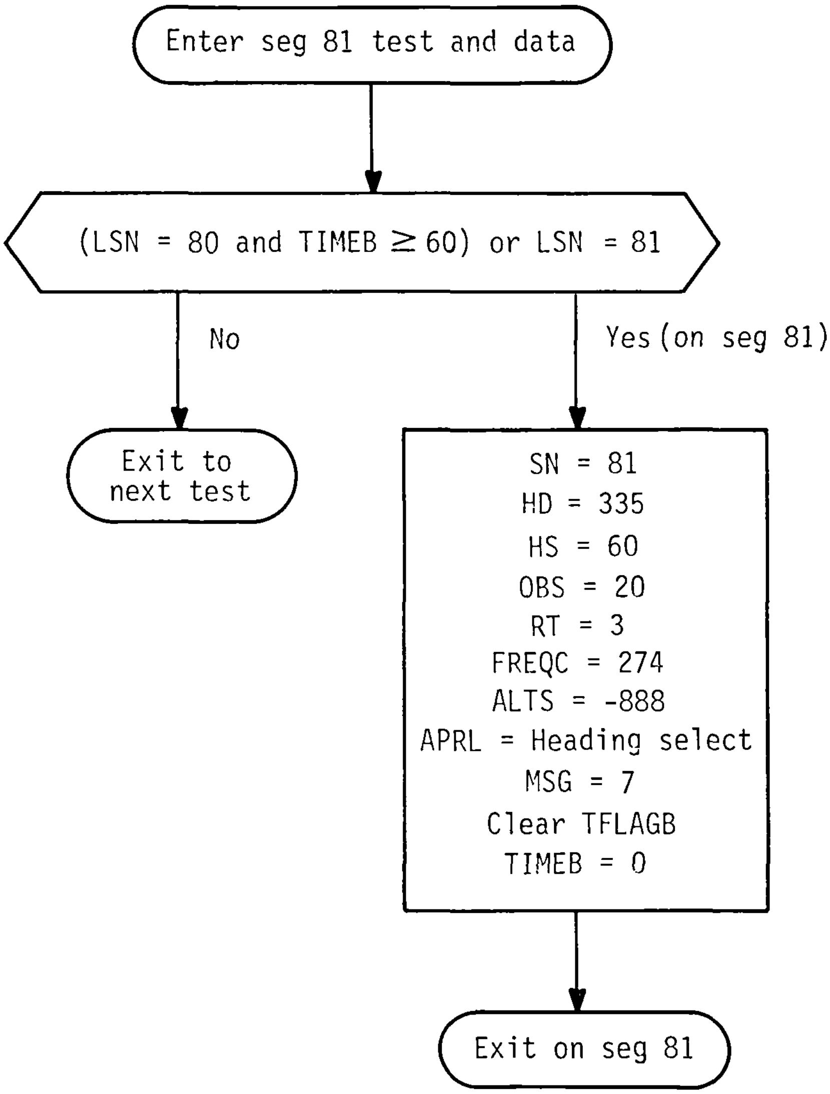

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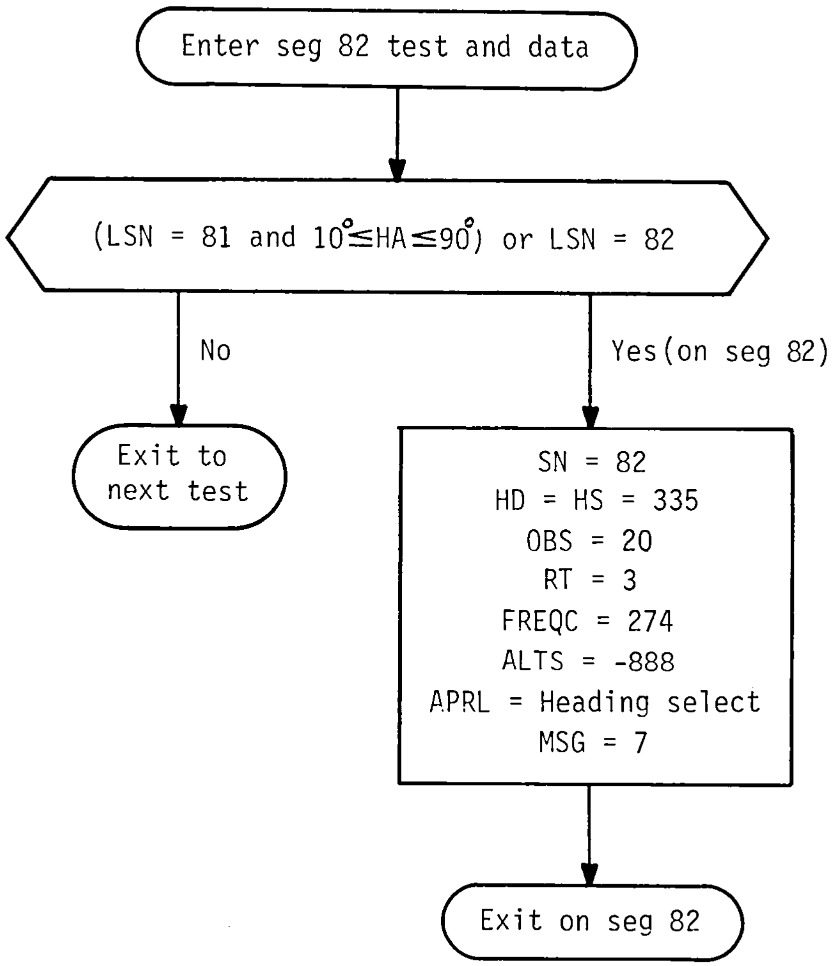

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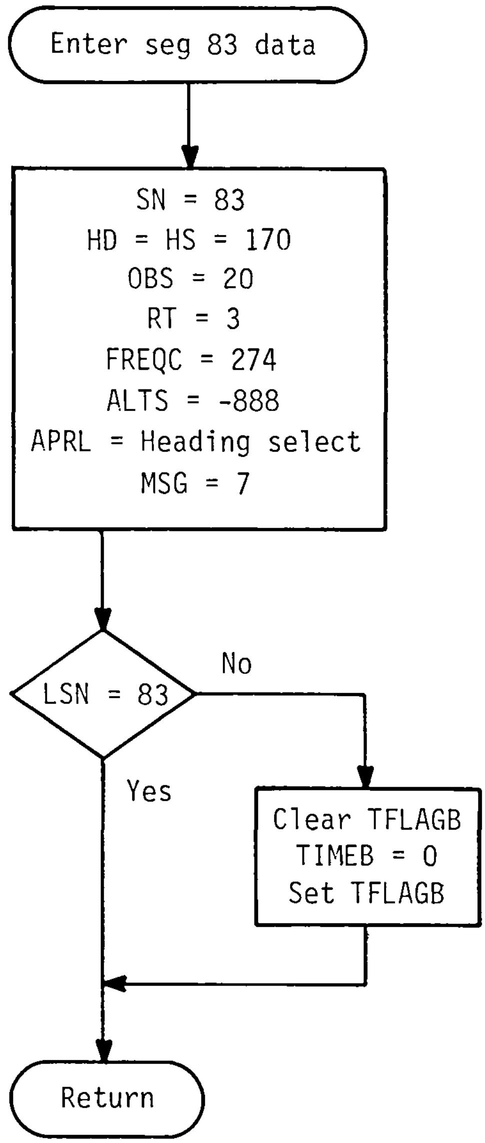

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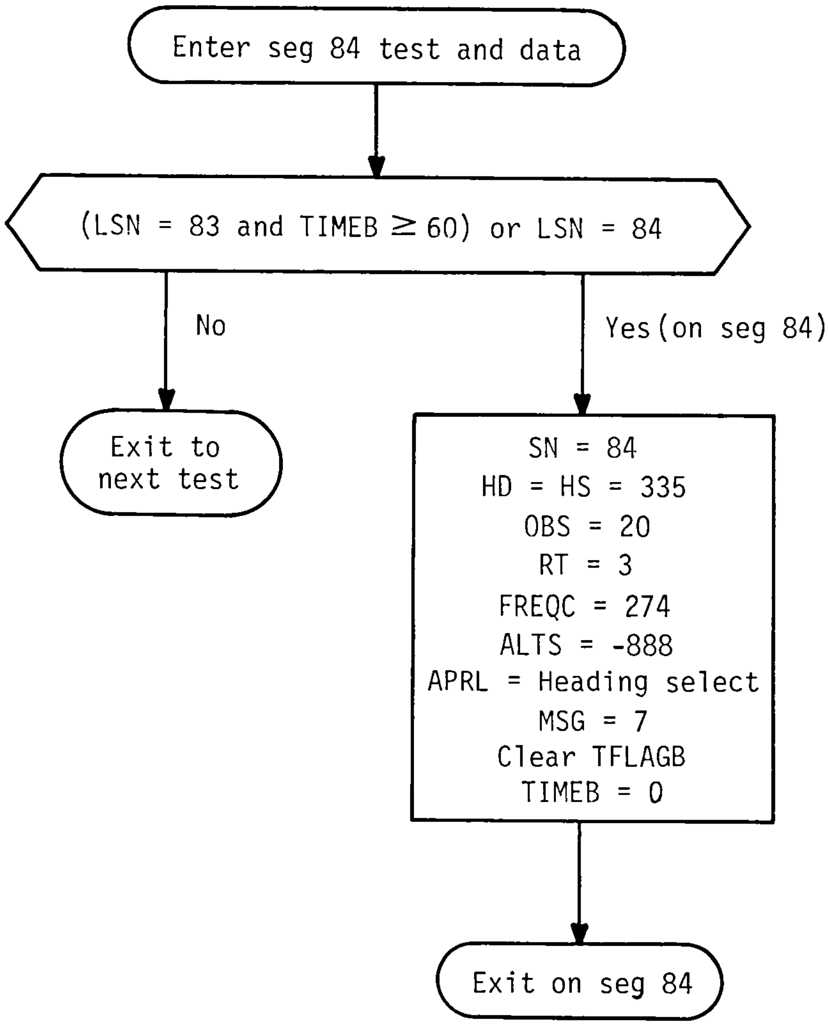

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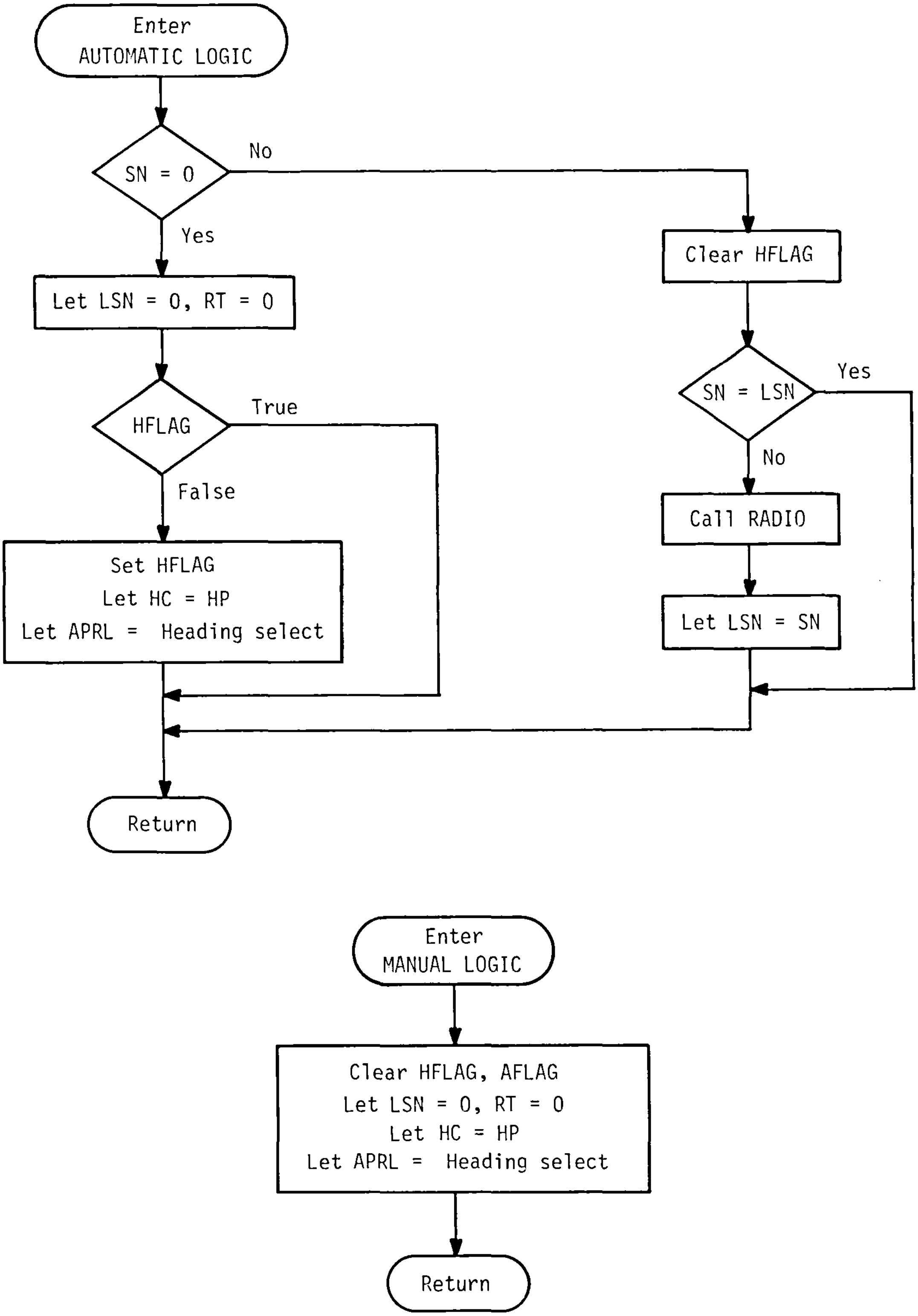

Figure 17.- Automatic and manual lateral-control subroutines.

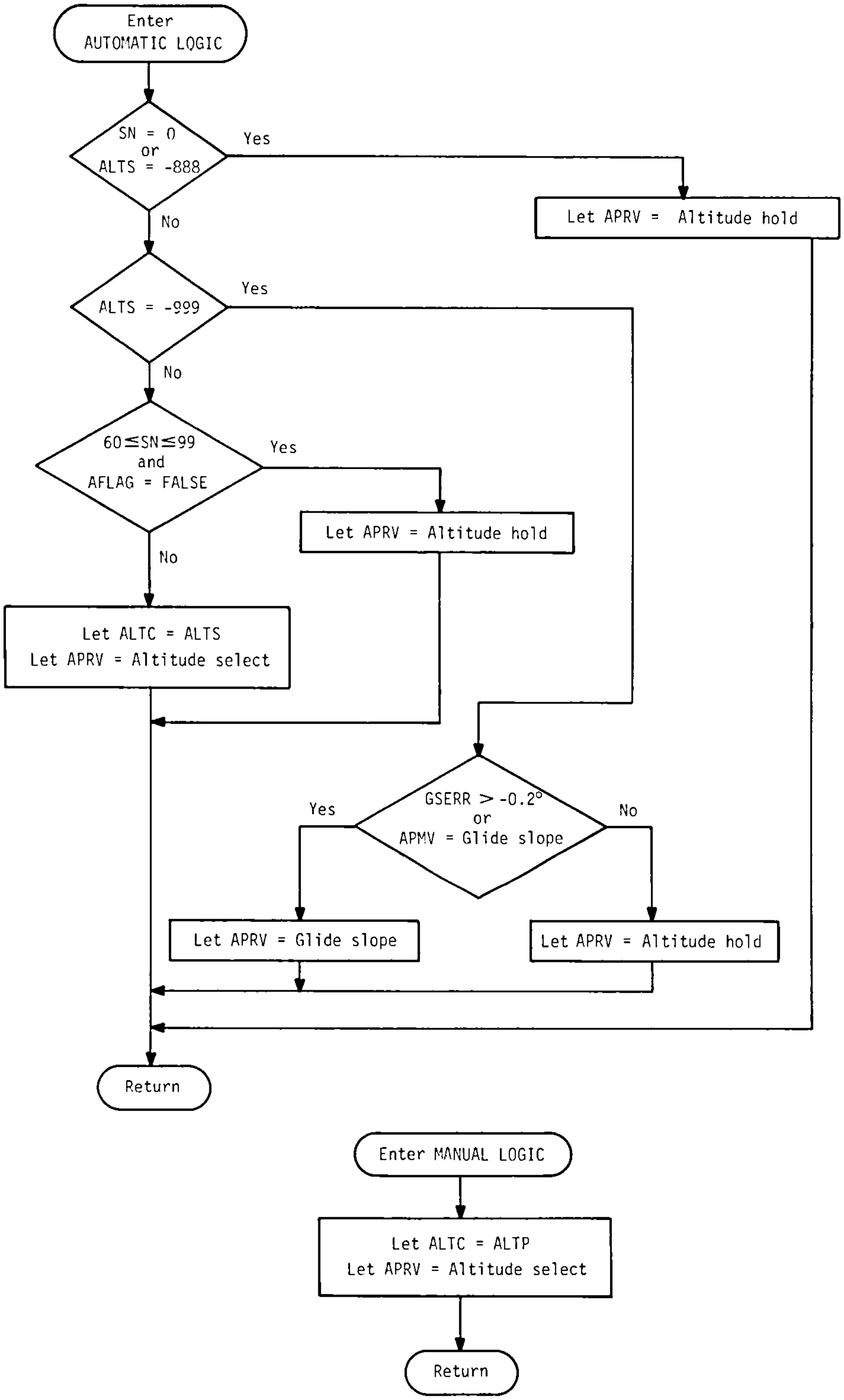

Figure 18.- Automatic and manual vertical-control subroutines.

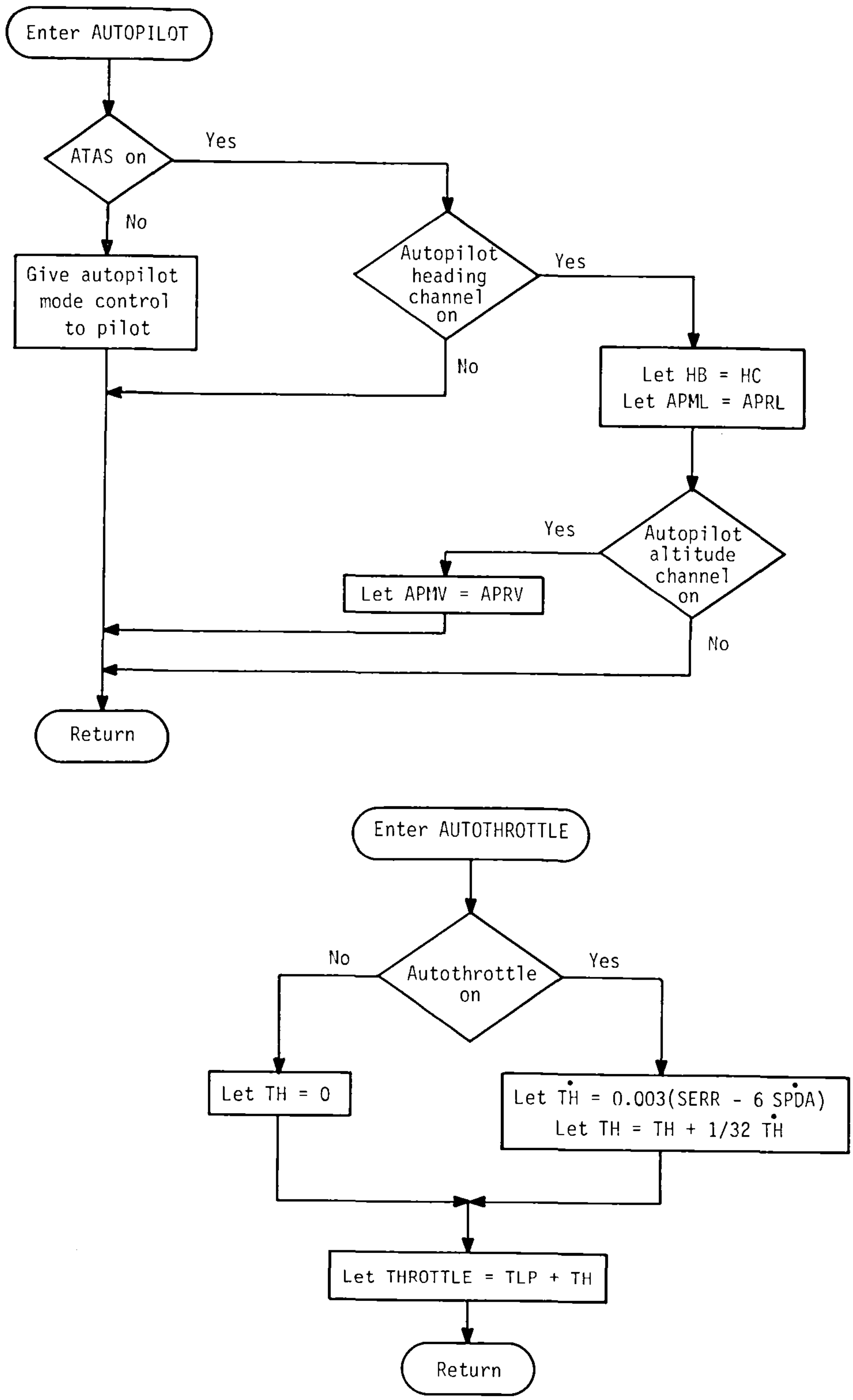

Figure 19.- Subroutines AUTOPILOT and AUTOTHROTTLE.

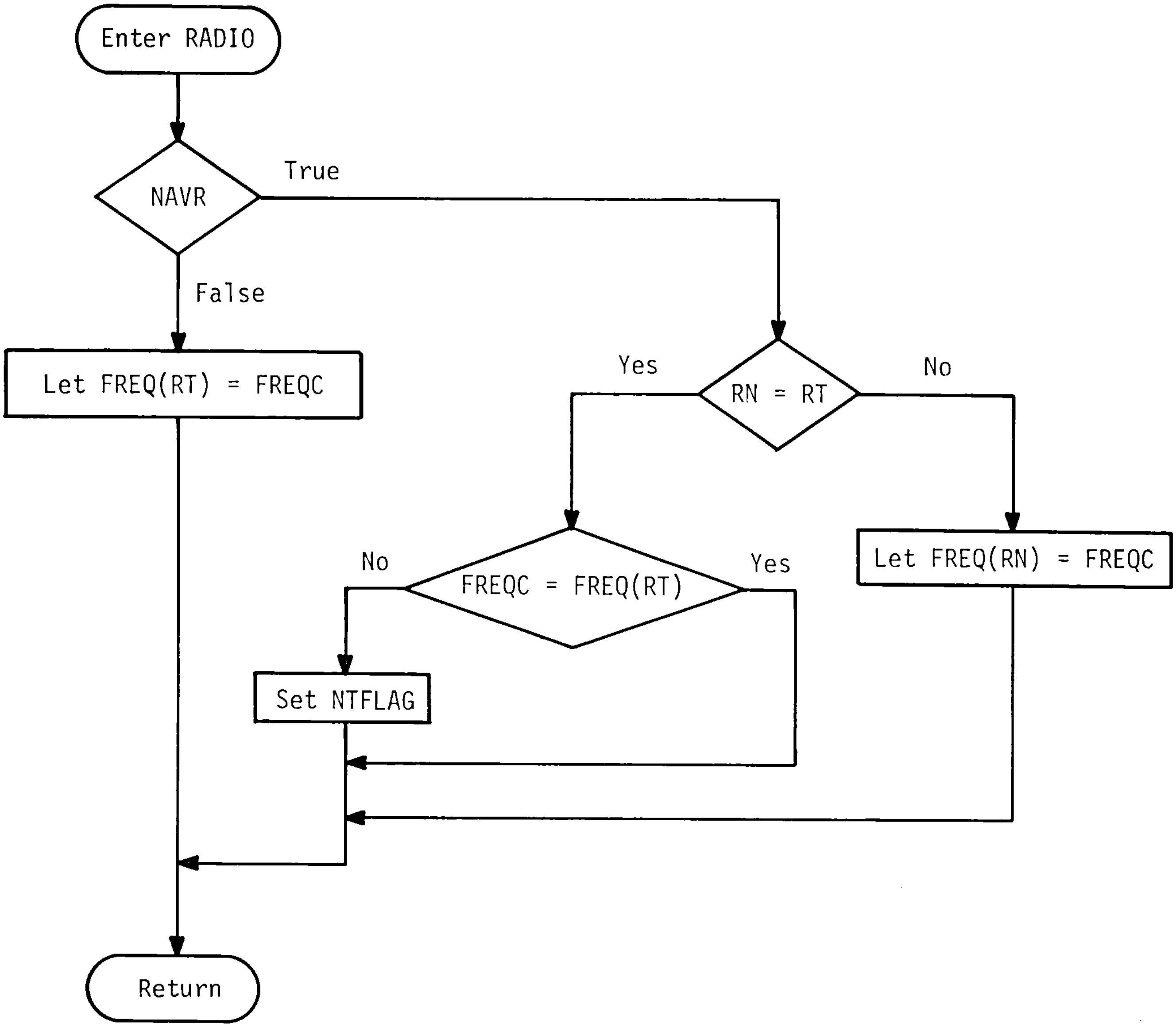

Figure 20.- Subroutine RADIO.

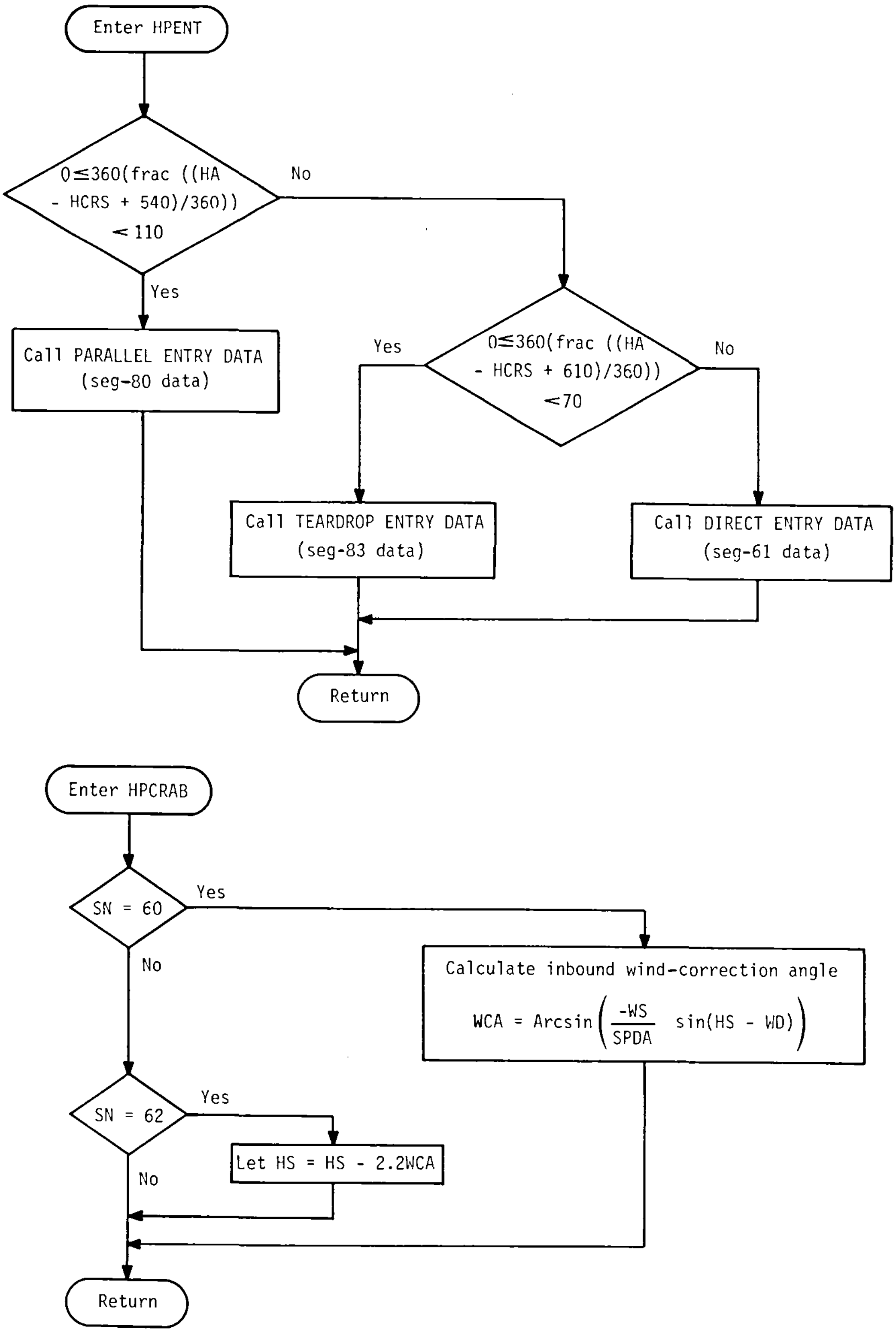

Figure 21.- Subroutines HPENT and HPCRAB.

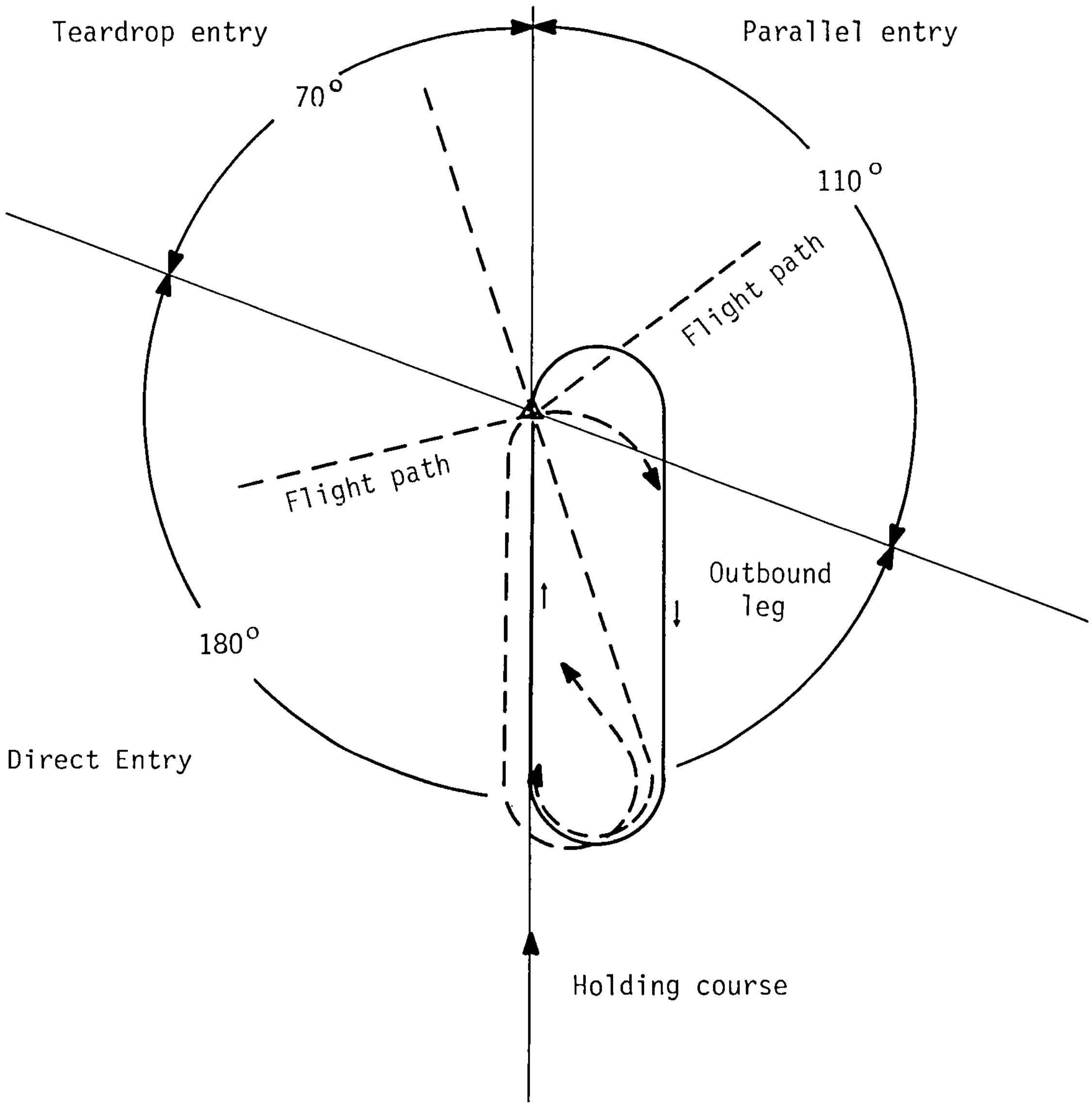

Figure 22.- Standard holding-pattern entries.

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16. Abstract

An effort is under way at Langley Research Center to improve the pilot-machine interface with aircraft automation to increase the safety and utility of single-pilot IFR (instrument flight rules) operations. An automatic terminal approach system (ATAS), that uses stored instrument approach data to automatically tune aircraft radios and control the aircraft autopilot, was conceived as a means of improving this critical interface. The ATAS automatically flies instrument approach procedures, including the missed approach, and provides for easy pilot interaction to accommodate air traffic control radar vectors and altitude assignments. A research prototype of an ATAS was developed to the extent necessary for a simulation implementation and piloted evaluation. This report describes the development of the ATAS concept and the software algorithms.

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